Radiation-Driven Dynamic Target Response for Dissimilar Material Jetting and for Debris Effects in Partitioned Pipes

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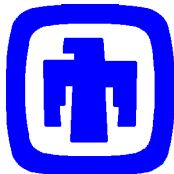| *Dissimilar Material Jetting on NOVA and Z*	*Debris Effects in Partitioned Pipes*
T. A. Mehlhorn, T. A. Haill, K. G. Budge, T. G. Trucano, K. R. Cochrane, J. J. MacFarlane	**M. D. Furnish, C. A. Hall, J. R. Asay, T. G. Trucano, K. G. Budge**

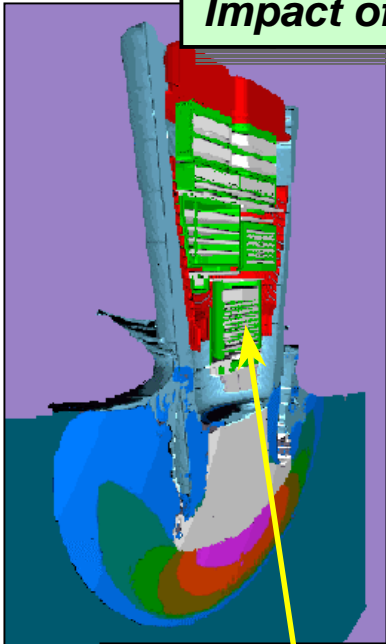# ALEGRA has unique capabilities for addressing SBSS program issues as well as HEDP problems.

Impact of Tactical Warhead

Detonation fronts

W-76 Fireset

4 μs

Radiation-Driven Jets

Critical components must survive the impact-induced shock loading

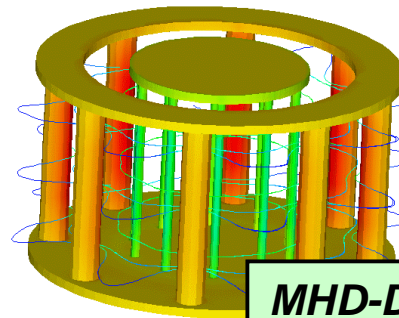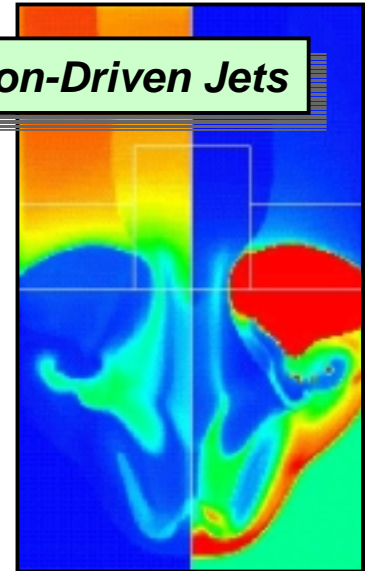**Dynamic Response of NG Power Supply**
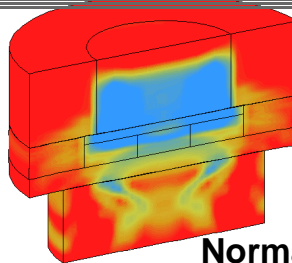
Normal stress (axial)
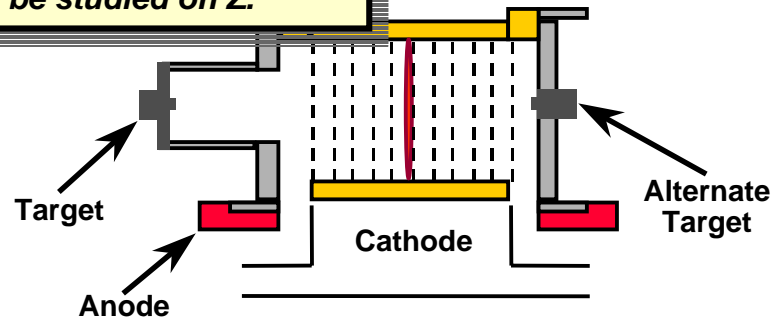
MHD-Driven Z Pinch

. . . the code combines solid dynamics, fracture, HE, etc., with high-energy features such as MHD and radiation transport.

Dissimilar Material Jetting on NOVA and Z

R. J. Lawrence,
T. A. Mehlhorn, T. A. Haill,
K. G. Budge, T. G. Trucano,
K. R. Cochrane, J. J. MacFarlane

**8 Nova laser beams
(16 TW total power)**

3-mm Scale-1 hohlraum

X-ray camera

Ti or Fe backlighter

Models have been validated by comparison with experimental results from NOVA.

Similar targets scaled up by an order of magnitude can be studied on Z.

Target

Alternate Target

Cathode

Anode

ALEGRA and SPECT3D are being used to calculate and visualize the experimental results of RadJet experiments on Z/ZBL.
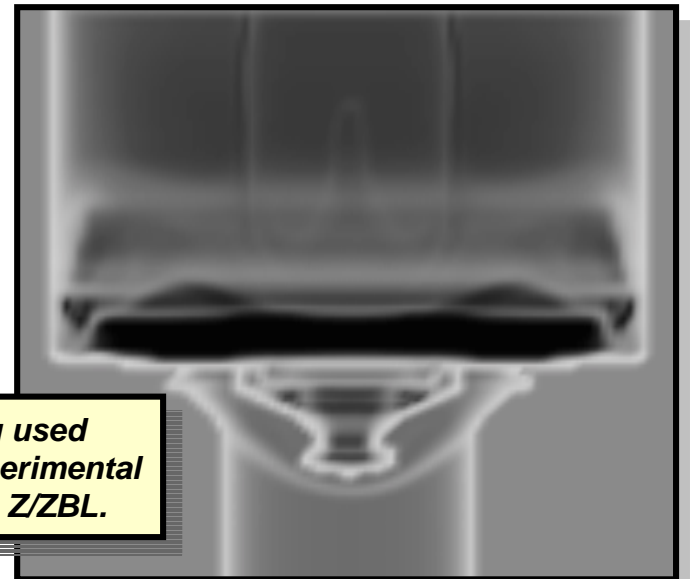
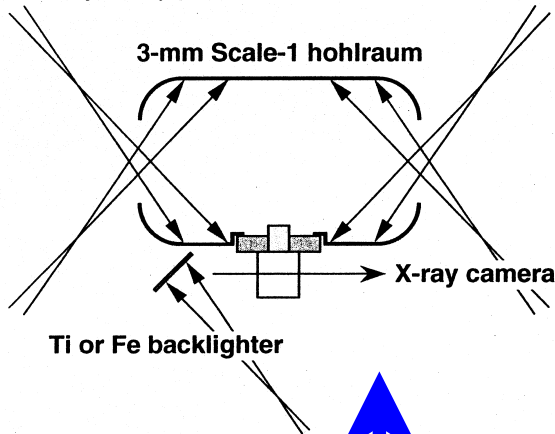# The NOVA experiments used radiation from a short-pulse, high-power, laser-driven hohlraum.
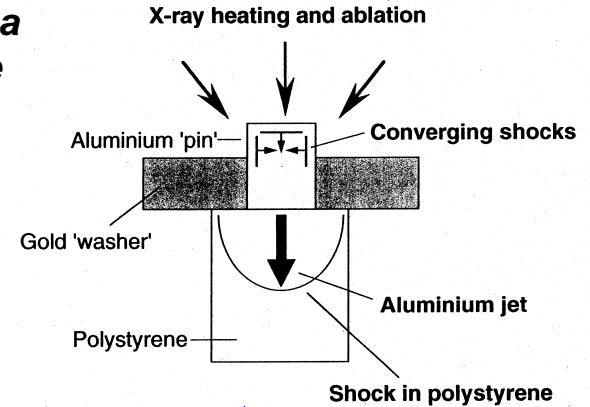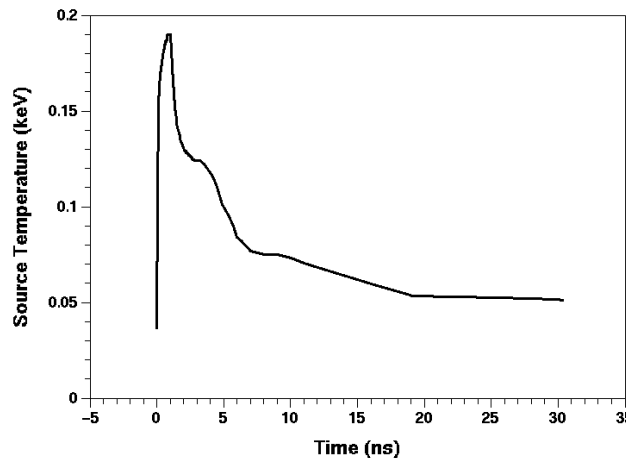
8 Nova laser beams (16 TW total power)

3-mm Scale-1 hohlraum

X-ray camera

Ti or Fe backlighter

The experiment used a laser-driven NOVA hohlraum to expose the sample to a short high-intensity radiation load. The sample response was observed with an x-ray backlighter.

The radiation drive was a blackbody temperature history peaking at ~190 eV with a FWHM pulse width of ~5 ns.

X-ray heating and ablation

Aluminium 'pin' **Converging shocks**

Gold 'washer'

Aluminium jet

Polystyrene

Shock in polystyrene

The target configuration consisted of a 150-μm-long aluminum "pin" in a 50-μm-thick gold "washer," which was backed with a 380-μm-diameter polystyrene block.
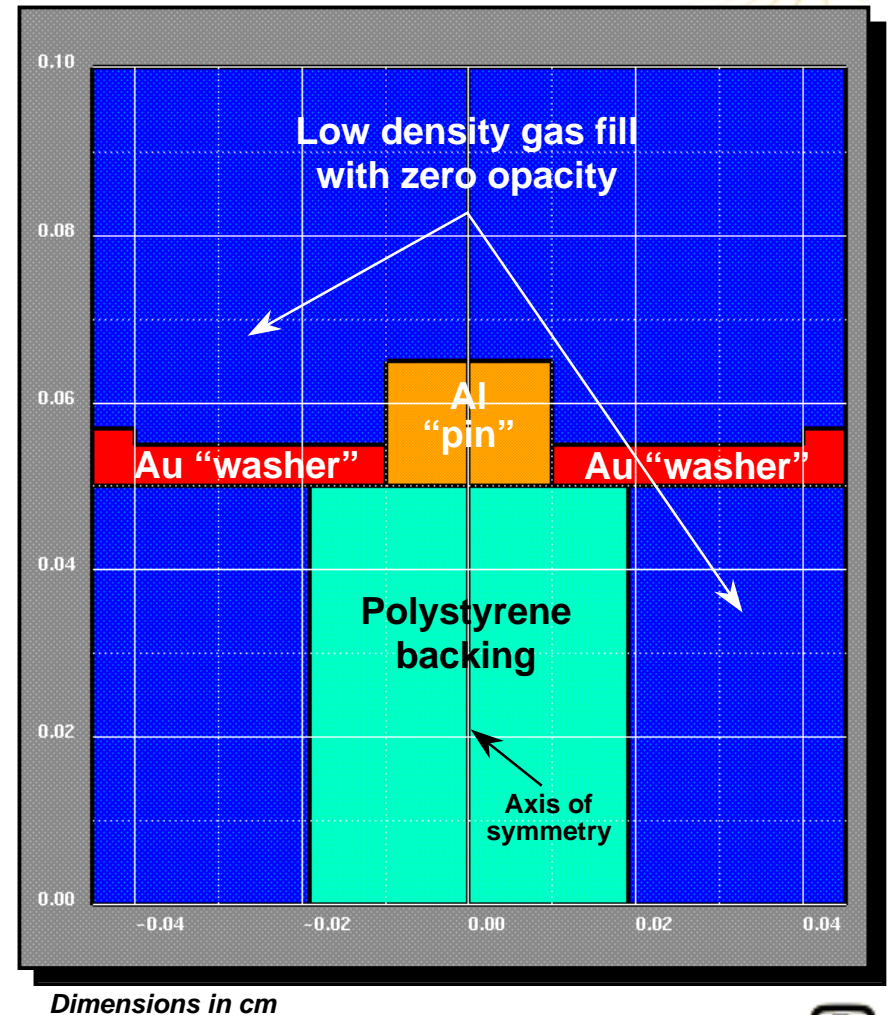
Z-pinch and Target Theory Department

- *For the NOVA problem, the thickness of the aluminum "pin" was 150 μm, the gold washer thickness was 50 μm, and the polystyrene backing had a diameter of 380 μm.*

- *We used a 2-D cylindrical Eulerian mesh with: 1) 4,500 elements (10-μm resolution); and 2) 18,000 elements (5-μm resolution).*

- *The radiation, incident from the top, was treated with single-group, SN_1 radiation transport, with radiation pressure disabled.*
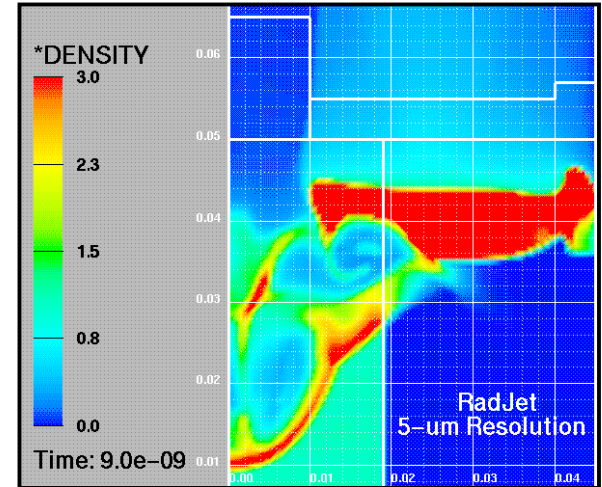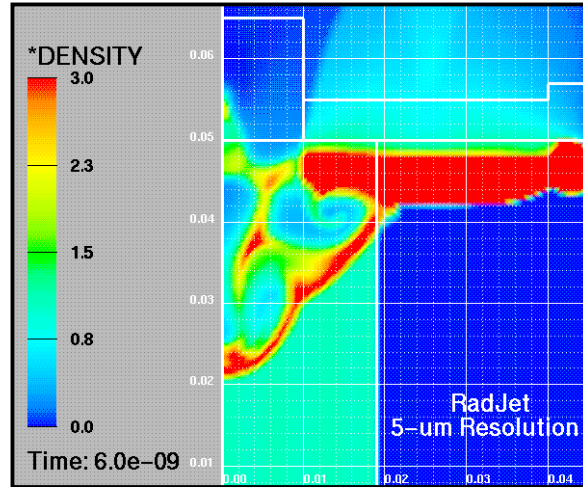

Dimensions in cm

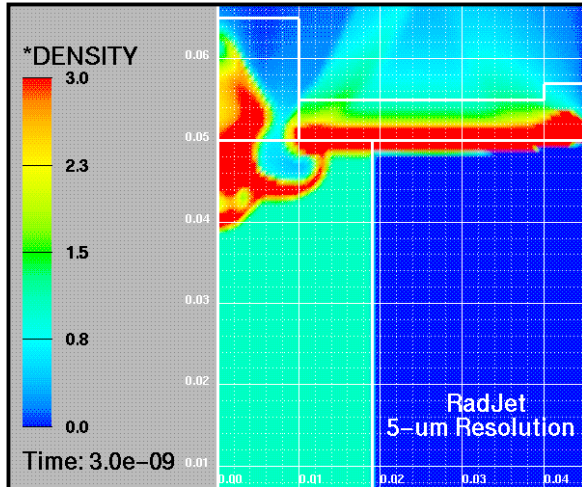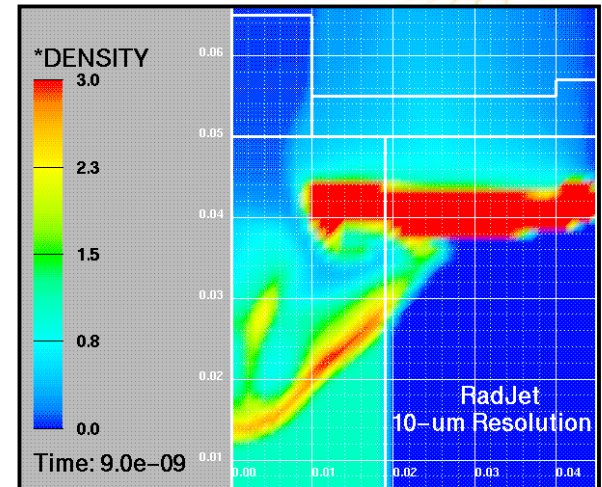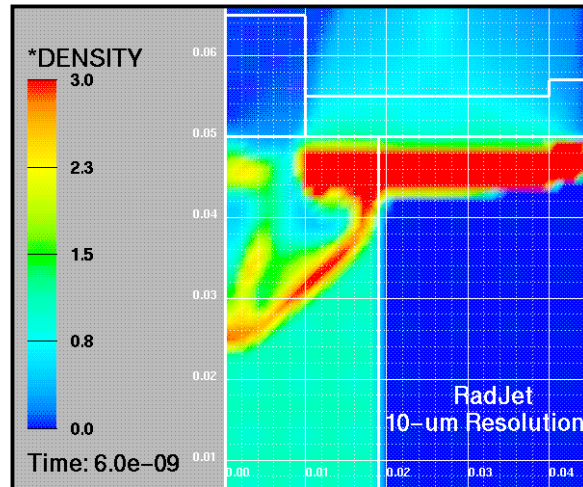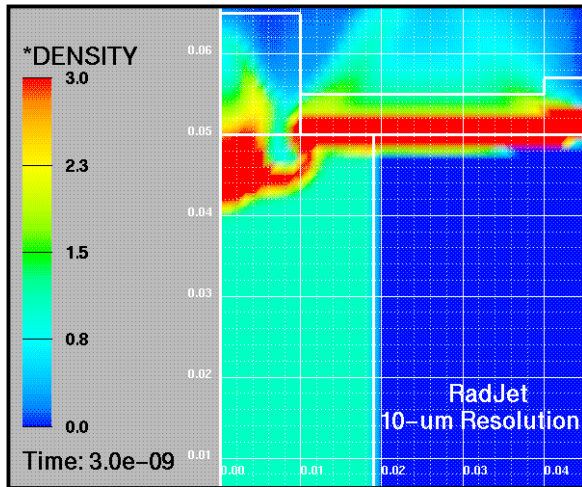# For NOVA, fine resolution calculations show more detail and slightly faster on-axis jet motion.

Z-pinch and Target Theory Department

Coarse resolution calculation ⟶

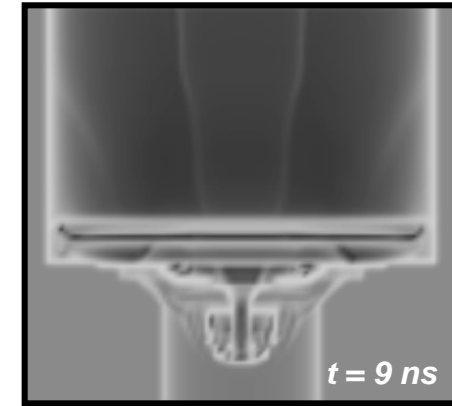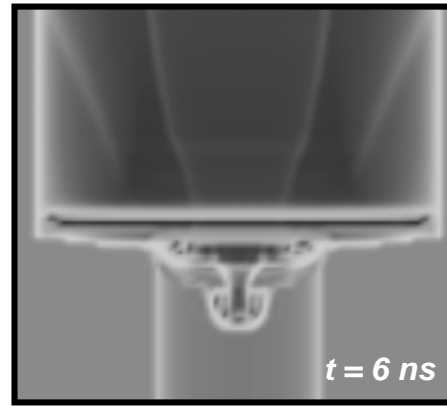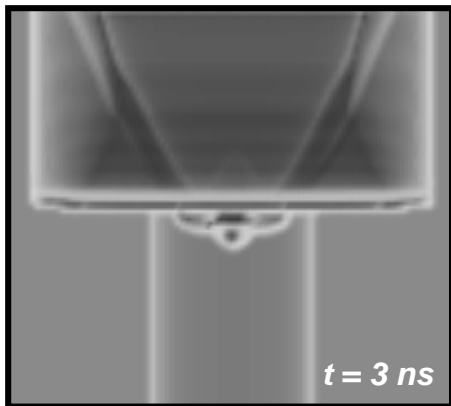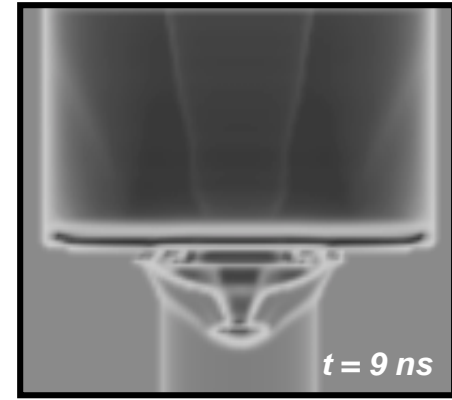
Fine resolution calculation ⟶

SPECT3D produces simulations of detector images from ALEGRA rad/hydro output.

Coarse resolution calculation ⟶

t = 3 ns

t = 6 ns

t = 9 ns

t = 3 ns

t = 6 ns

t = 9 ns
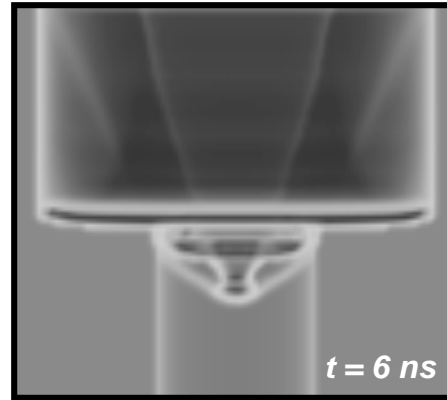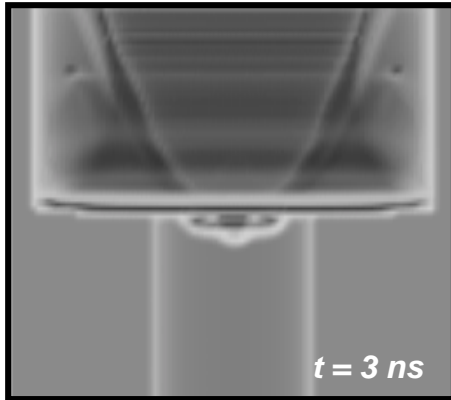
Fine resolution calculation ⟶

For this configuration the ALEGRA results are consistent with other codes and the experiment.

Spatial characterization of aluminum jet (Revised configuration – coarse mesh):

[Axial position of leading edge (μm)]

Code	ALEGRA (Eulerian)	PETRA (Eulerian)	CALE (ALE)	RAGE (AMR)	Experiment (Estimated)
Time = 6 ns	265	245	300	280	~260
Time = 9 ns	380	345	405	380	300+
Time = 12 ns	460	–	–	–	–

- *At a computational time of 6 ns, ALEGRA predicts the on-axis jet location within about 2% of the estimated experimental result; this result is also consistent with the other computational efforts.*

- *At a time of 9 ns the predicted axial location of the jet is somewhat over 20% greater than the estimated experimental measurement; but as with the earlier time, it agrees very closely with the average of the other code results.*

We are now studying the scaling of these RadJet experiments from NOVA to Z.
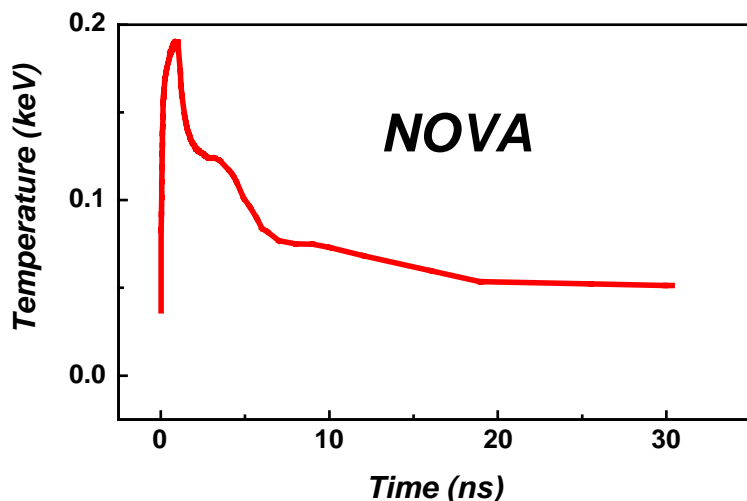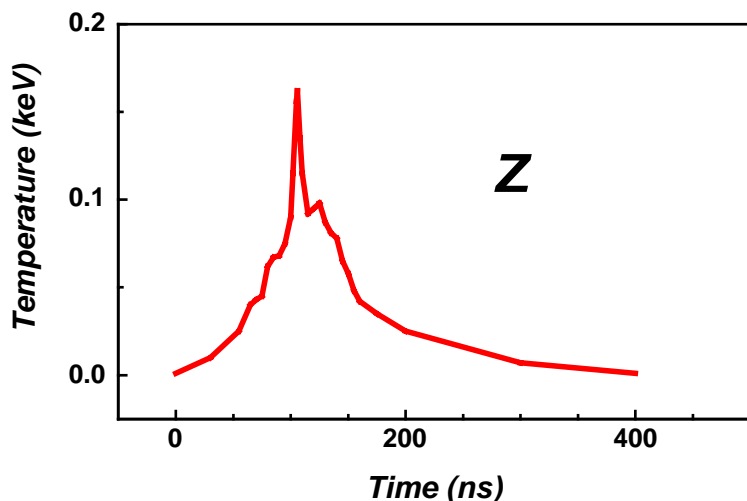
Typical Source Characteristics

Peak temperature:

NOVA	~190 eV
Z	~162 eV

FWHM pulse width:

NOVA	~5 ns
Z	~50 ns

Peak power:

$$P_{MAX}(Z)/P_{MAX}(NOVA) \approx 1/2$$

Total energy fluence:

$$\Phi_{TOT}(Z)/\Phi_{TOT}(NOVA) \approx 3$$

- *Similar mechanical behavior should be obtained by scaling the physical dimensions by about a factor of ten.*

- *However, the radiation transport will not scale in a similar fashion.*

- *Source for Z can be modified.*

Integrating the temperature curves allows the fluences to be compared.

Z-pinch and Target Theory Department

$$\Phi = \sigma \int T^4(t)\, dt$$

Z-Pinch

NOVA

NOVA (Shifted)
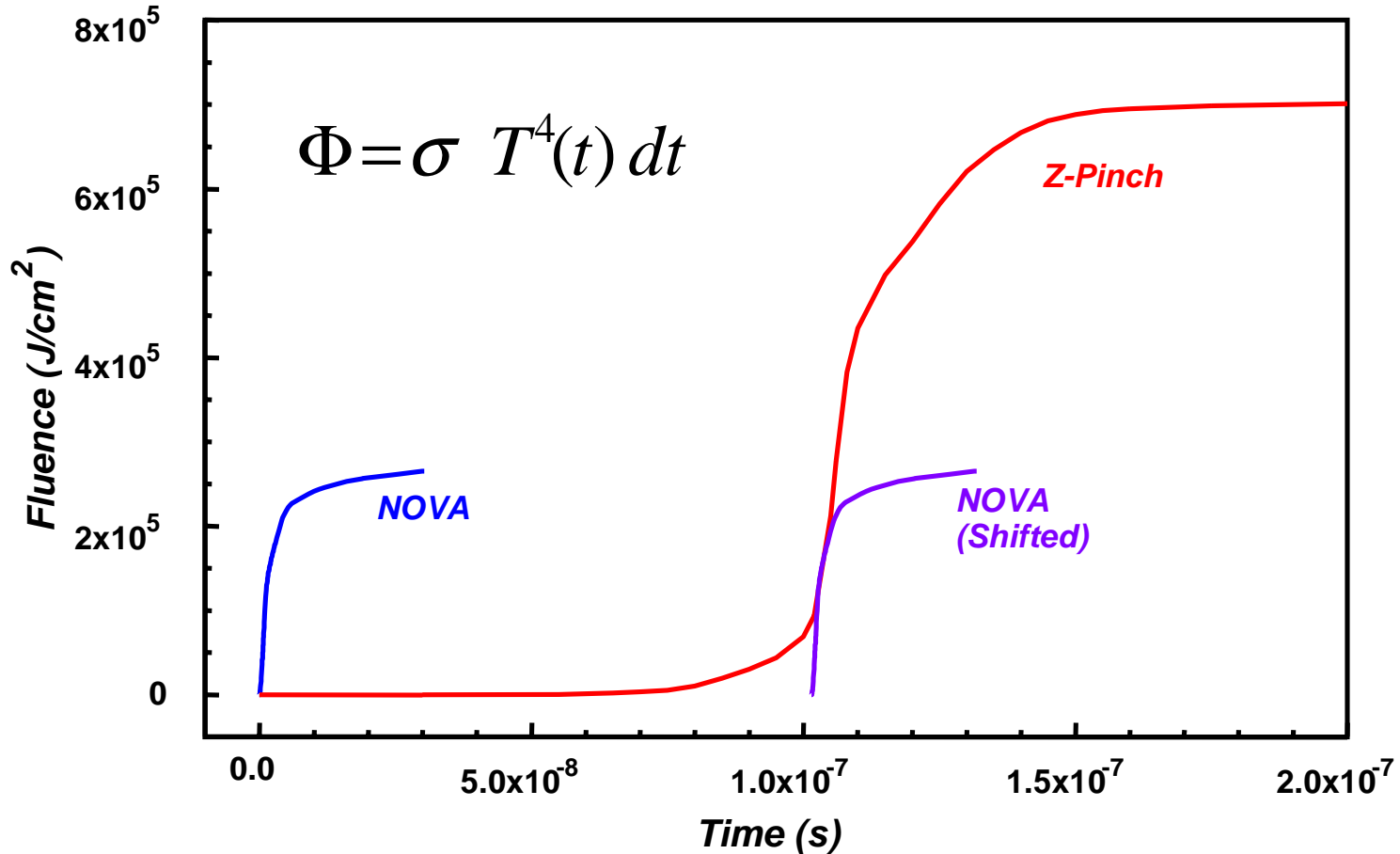
The Z experiments would use a longer pulse, but a higher energy Z-pinch-driven hohlraum.

Wire Array

Hohlraum

Secondary Hohlraum

Wire Array

Primary Hohlraum

Target

Cathode

Alternate Target

Anode Plate
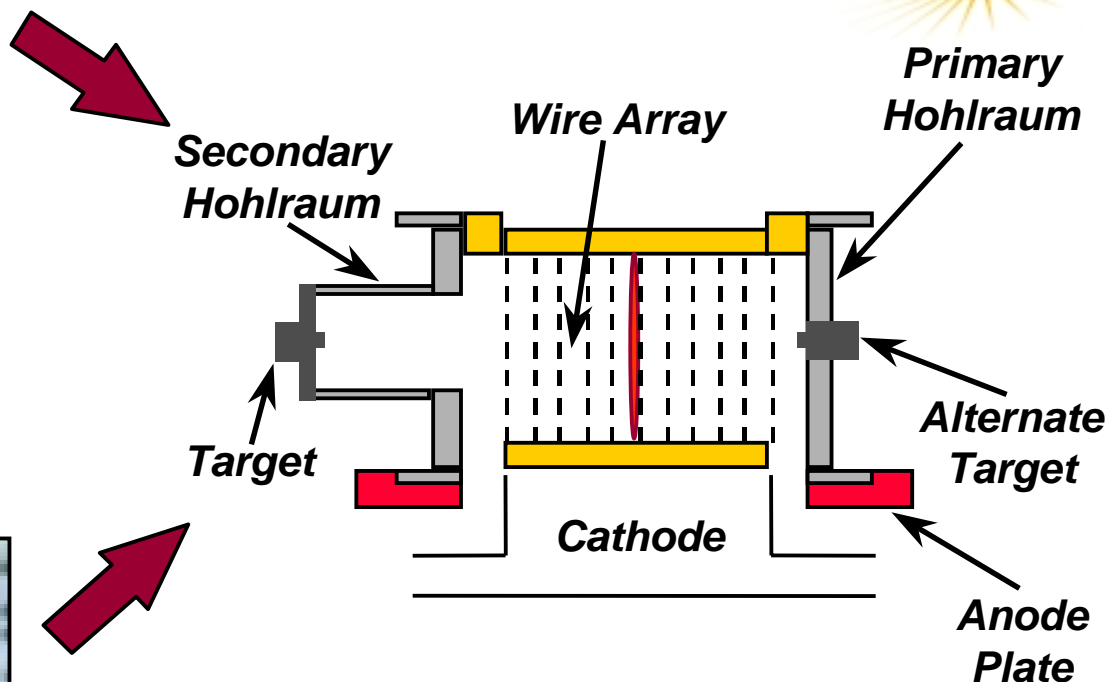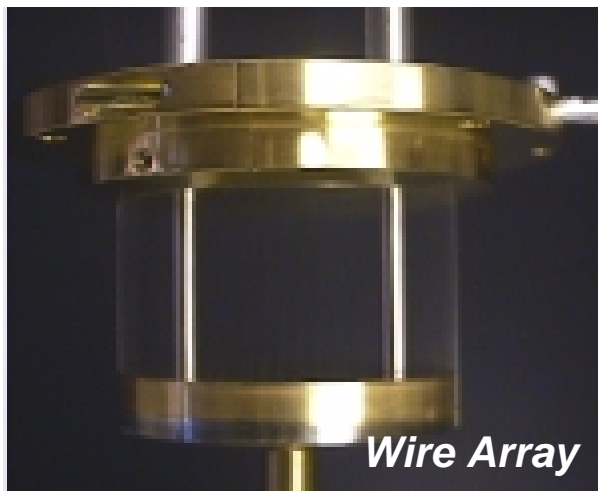
- *The target could be placed in either the primary or a secondary hohlraum.*

- *Principal diagnostics would involve the Z-Beamlet Backlighter that is presently under construction.*

There are several points that should be noted with regard to the calculations.

- **The quoted half-max pulse widths are only approximate, but lead to about a factor of ten difference in characteristic response times.**

- **In these calculations the physical dimensions are scaled by exactly a factor of ten for the two cases.**

- **Because the radiation transport phenomena (*e.g.,* opacities) do not scale in the same manner as the hydrodynamic behavior, the total response will not be directly homologous.**

- **The calculations were run with ALEGRA, using 10-μm resolution for the NOVA case and 100-μm resolution for the Z configuration.**

- **Because of the initial slow rise for the radiation drive from Z, the times cannot be shifted in a directly proportional fashion; the comparison plots were chosen for similar stages in the evolution of the response.**

The RadJet problem at very early times, with the shock part way through the "pin" . . .

RadJet / NOVA:
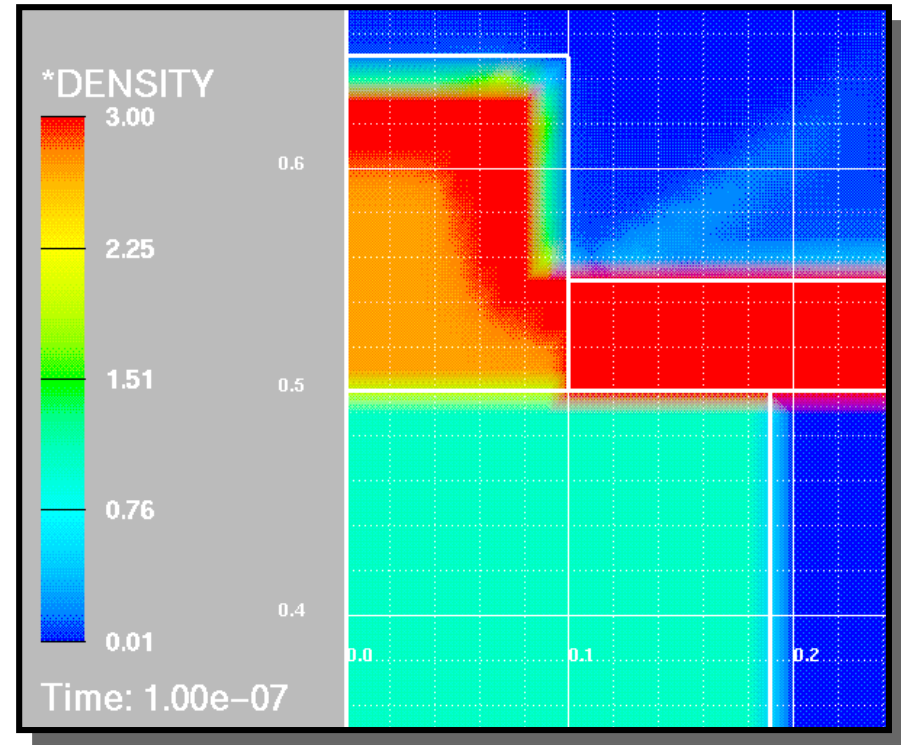
RadJet / Z:

Dimensions in cm

The RadJet problem at early times, at about the time of shock breakout . . .

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RadJet / NOVA:

rj-20-3

RadJet / Z:

rjz-30-3

Dimensions in cm

01/29/2001 • rjl asci/alegra; 14

The RadJet problem at medium time, after the "jet" is relatively well formed . . .

RadJet / NOVA:

rj-20-3

*DENSITY
3.00
2.25
1.51
0.76
0.01
0.06
0.05
0.04
0.00   0.01   0.02
Time: 3.00e−09

RadJet / Z:

rjz-30-3

*DENSITY
3.00
2.25
1.51
0.76
0.01
0.6
0.5
0.4
0.0   0.1   0.2
Time: 1.66e−07
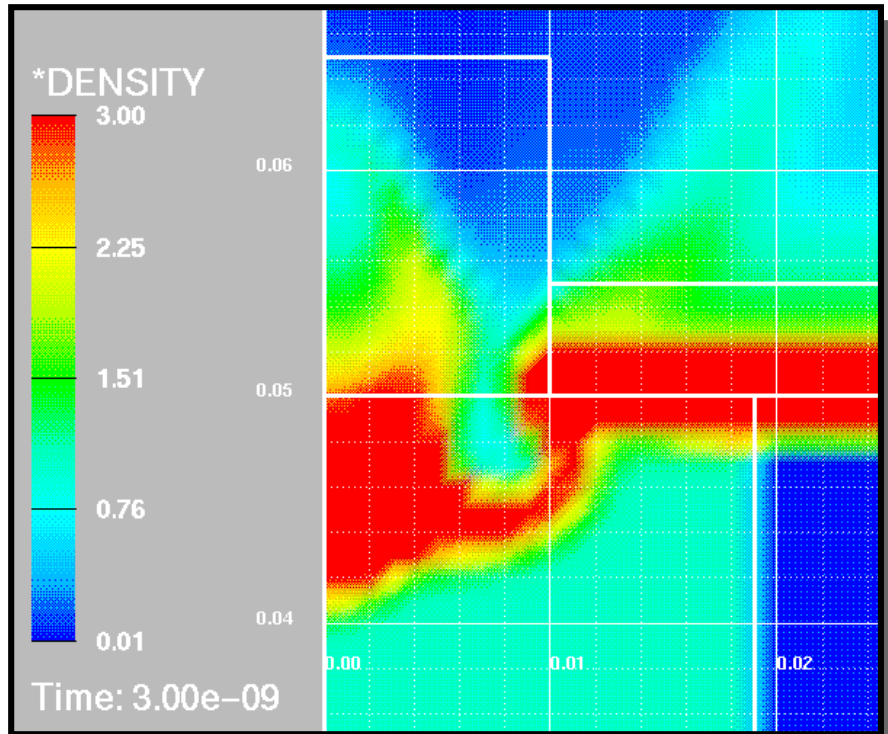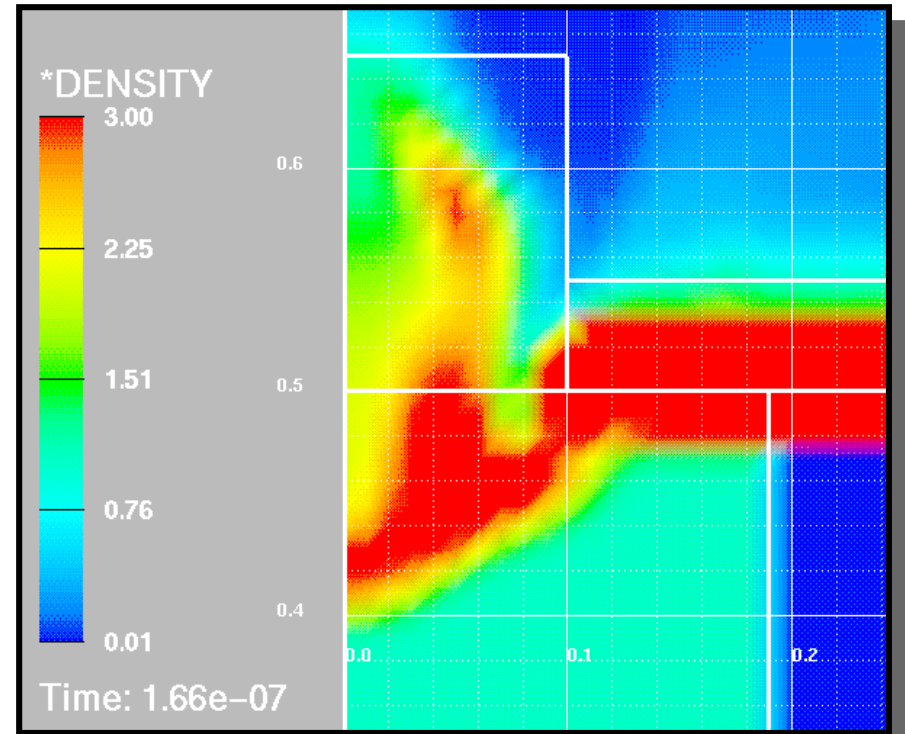
Dimensions in cm

At later times the problems are still similar, and the jet is well into the polystyrene backing.

RadJet / NOVA:

rj-20-3

*DENSITY
3.00
2.25
1.51
0.76
0.01

0.06
0.05
0.04

0.00   0.01   0.02

Time: 4.00e−09

RadJet / Z:

rjz-30-6

*DENSITY
3.00
2.25
1.51
0.76
0.01

0.6
0.5
0.4

0.0   0.1   0.2

Time: 1.87e−07
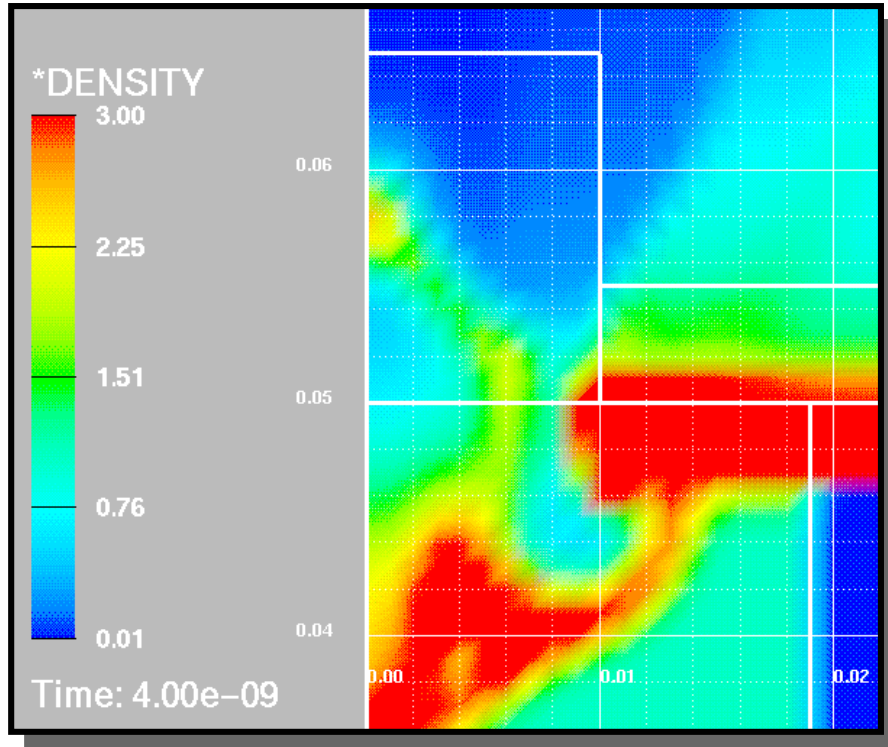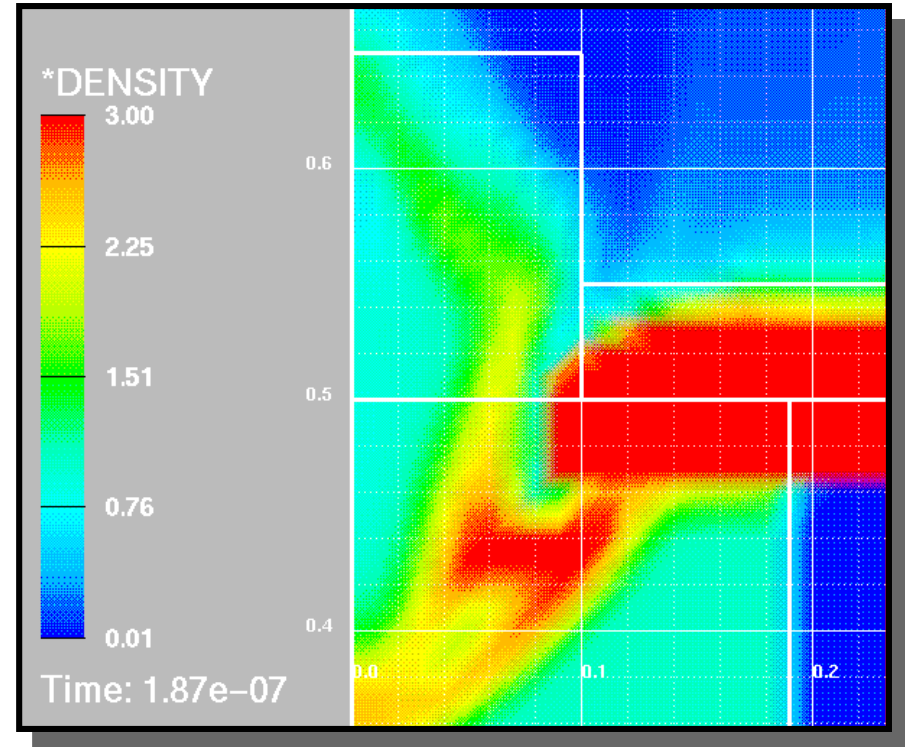
Dimensions in cm

By late times, the differences due to lack of radiation "scaling" are considerably more evident.
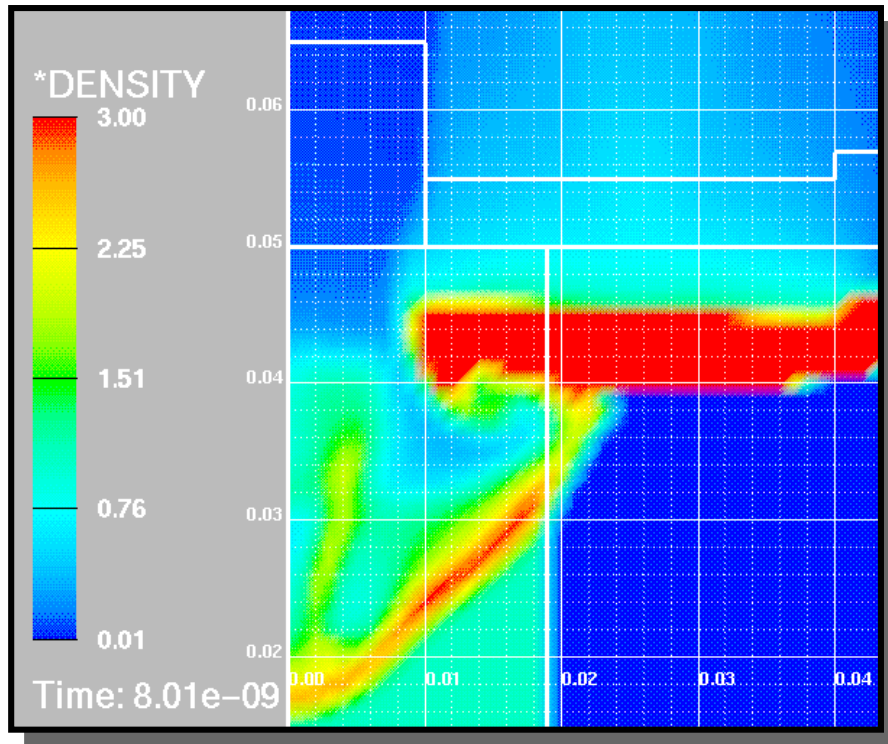
RadJet / NOVA:
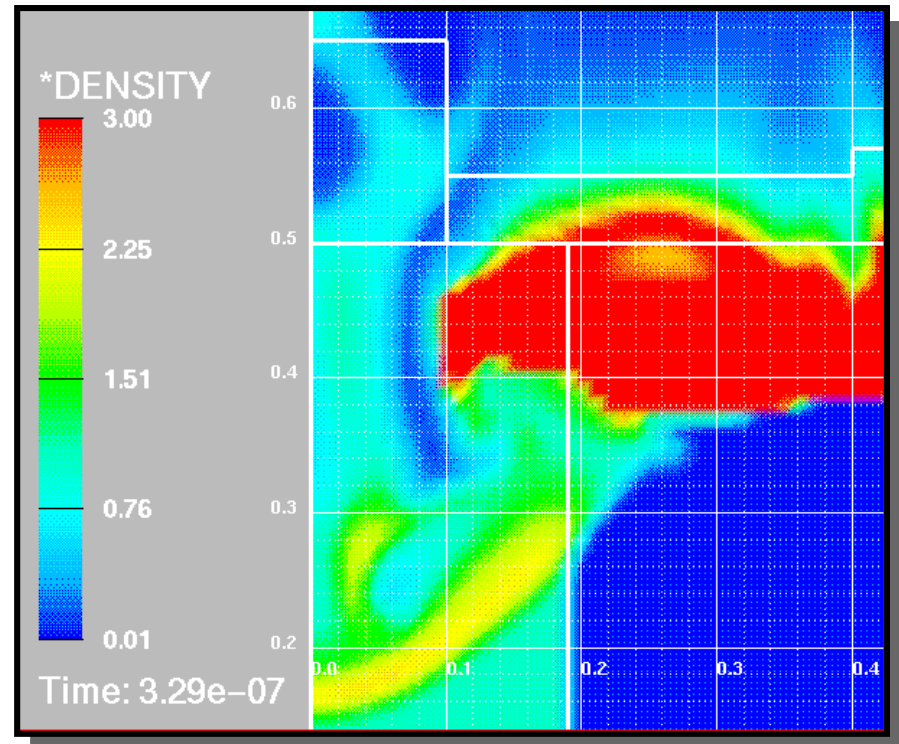
RadJet / Z:

Dimensions in cm

Temperatures and pressures show much larger differences than the densities.

RadJet / NOVA:

'T' -- $T_{max} \cong 130$ eV
'P' -- $P_{max} \cong 30$ Mb
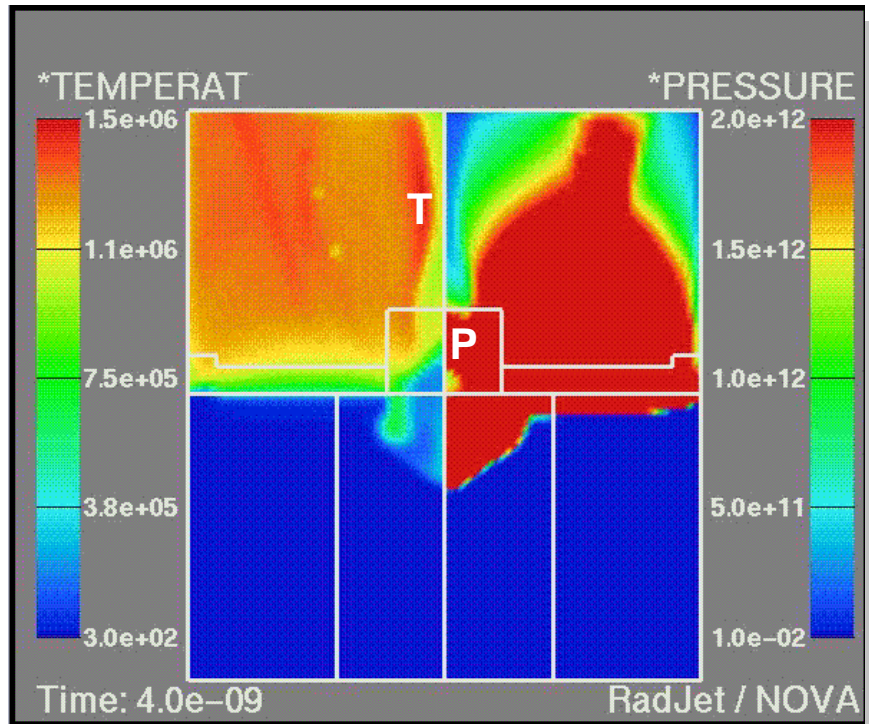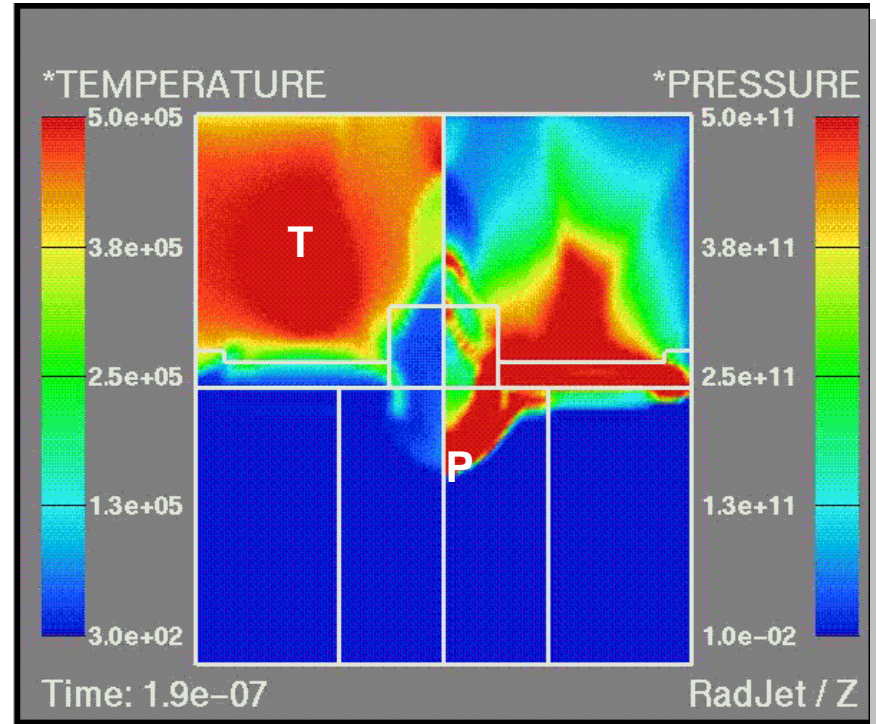
RadJet / Z:

'T' -- $T_{max} \cong 50$ eV
'P' -- $P_{max} \cong 3$ Mb

At much later times there are significant differences, but many qualitative features are similar.

Z-pinch and Target Theory Department

RadJet / NOVA:

'T' -- $T_{max} \cong$ 70 eV
'P' -- $P_{max} \cong$ 4 Mb
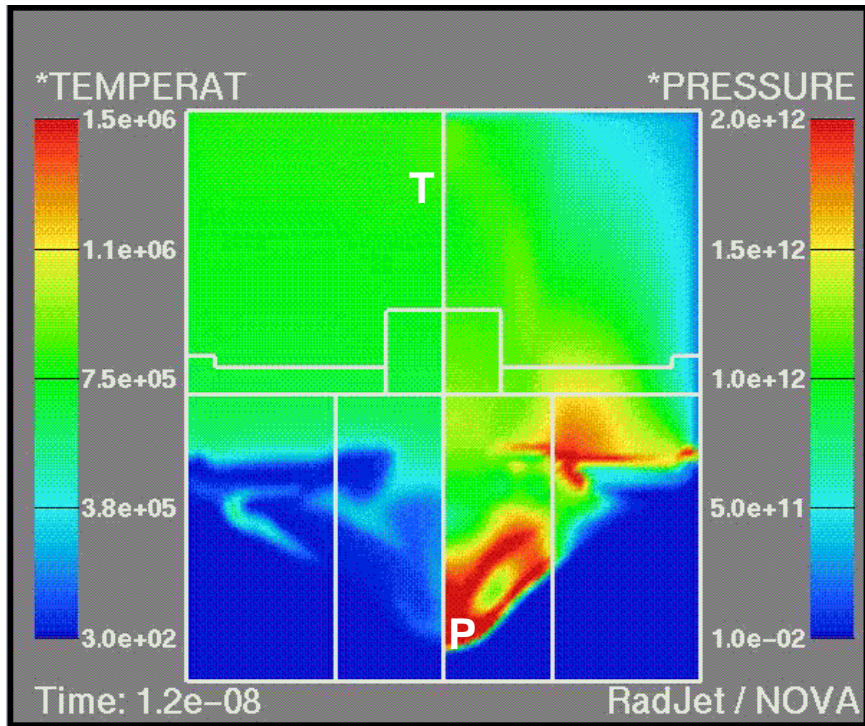
RadJet / Z:
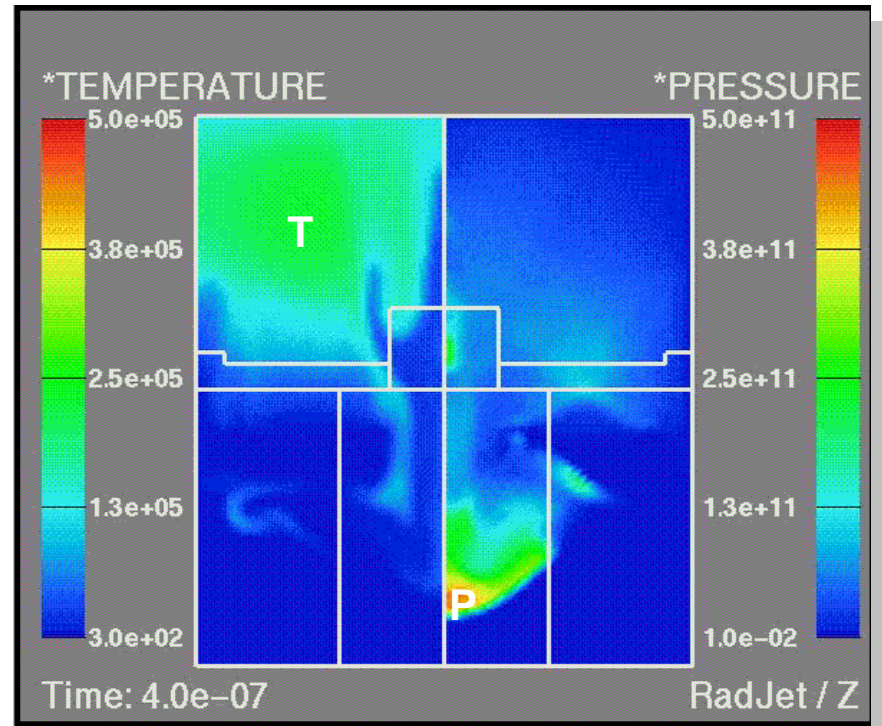
'T' -- $T_{max} \cong$ 20 eV
'P' -- $P_{max} \cong$ 0.5 Mb

The Z-Beamlet Backlighter (ZBL) is scheduled to begin operation on Z in early 2001.

- *Construction of the ZBL building began in March 1999.*

- *Construction of the ZBL building was completed in October 1999.*

- *The front end activation was completed in February 2000.*

March 2000

March 1999

Sept 2000

The ZBL will be an important new diagnostic tool for high energy density physics experiments on Z.

Z-pinch driven hohlraum

Physics package

Laser backlighter

Detector
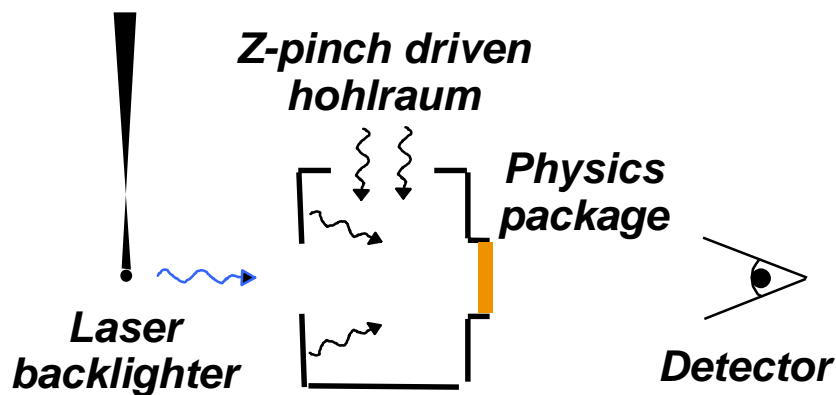
2 TW laser backlighter on Z --

Z-Beamlet
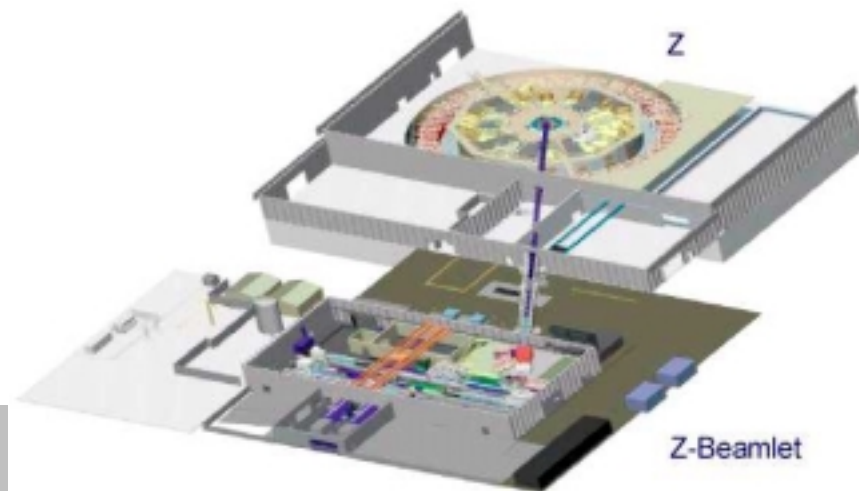
Measurements possible with a backlighter:

- **Material T_e and n_e**
- **Magnetic Rayleigh-Taylor growth rate**
- **Absorption spectrum**
- **Capsule implosion symmetry**
- **Material interface motion**
- **Particle velocity and shock density**
- **Instability mix region**

- **Capabilities include both point projection and area backlighting.**
- **We will have spatial resolution of 25 μm at 9 keV x-ray probe energy.**

We are using SPECT3D to visualize the use of the Z-Beamlet Backlighter (ZBL) on these experiments.

Z-pinch and Target Theory Department

- *The amplitude of each cell represents the optical depth through the jet as a function of axial position (Y) and offset from the axis (X).*

- *Overall, ZBL performance depends on photon energy, conversion efficiency, and other issues.*

- *This plot is taken from the 100-μm resolution RadJet / Z calculation at a time of 330 ns.*

- *For this example the backlighter energy was chosen as 3 keV, but the jet is probably too thick to "see" through.*
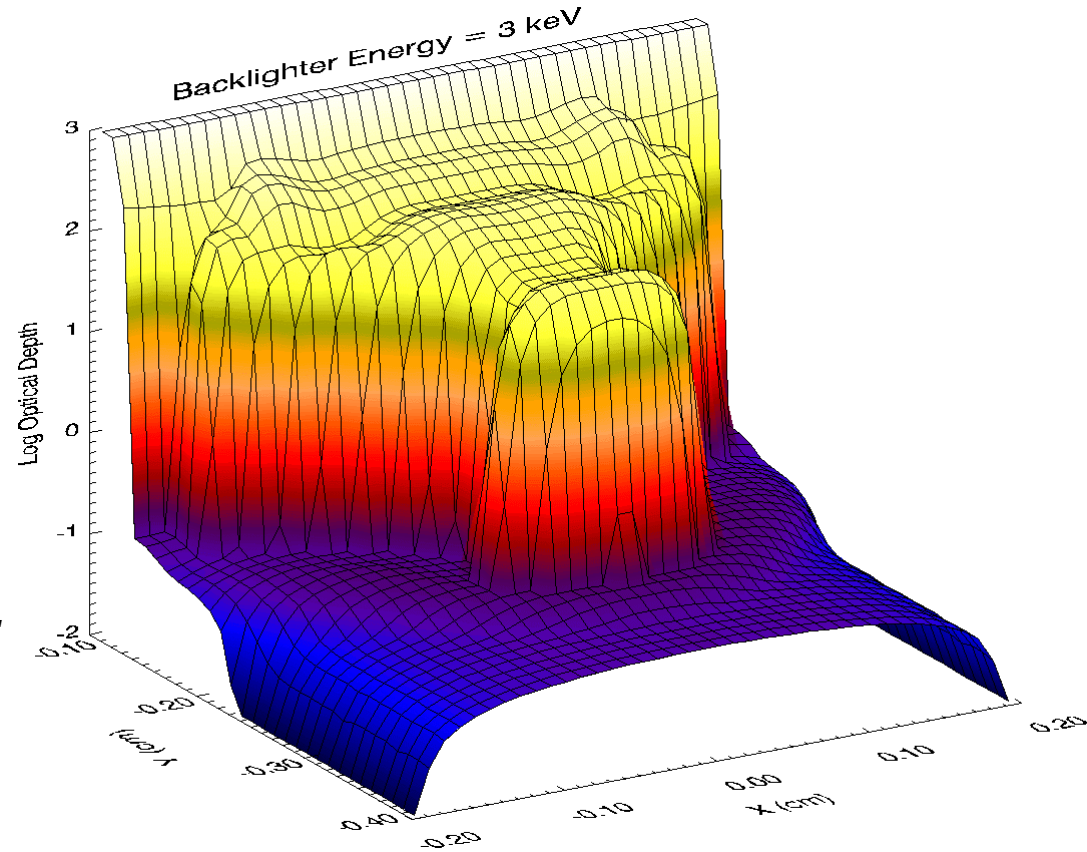
At late times and 10 keV, we get optical depths of order unity, which implies experiment is feasible.

Backlighter photon energy: $h\nu = 10$ keV

t = 330 ns

t = 528 ns
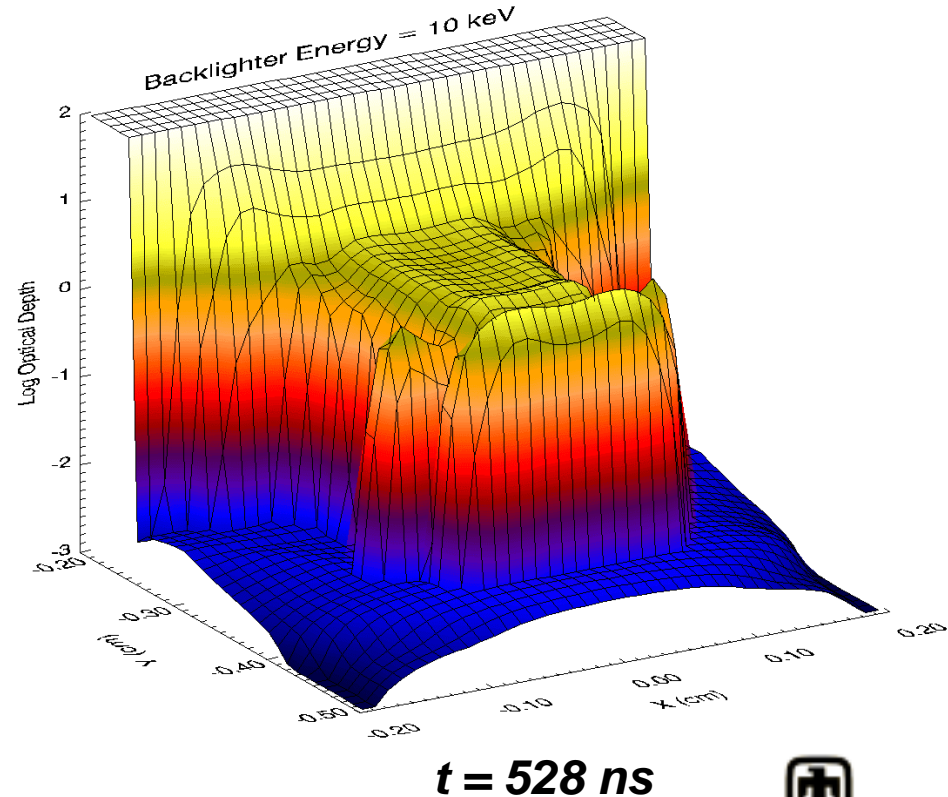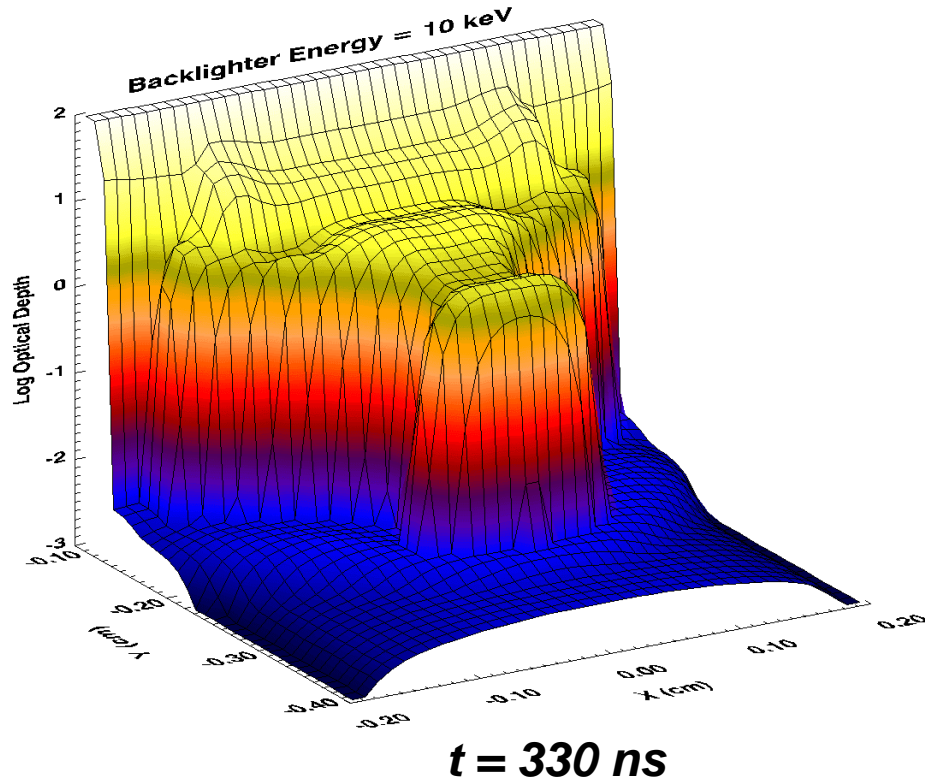
Simulations of detector output from the scaled-up Z runs show all major features.

Z-pinch and Target Theory Department

- *These images were generated with $h\nu = 10$ keV.*

- *Features evident in the radiographs include the polystyrene backing block, the shock wave in the polystyrene, and details of the aluminum jet in the plastic.*

- *Details of the blowoff moving back into the hohlraum are also evident, but would not be recorded in the experimental radiograph.*
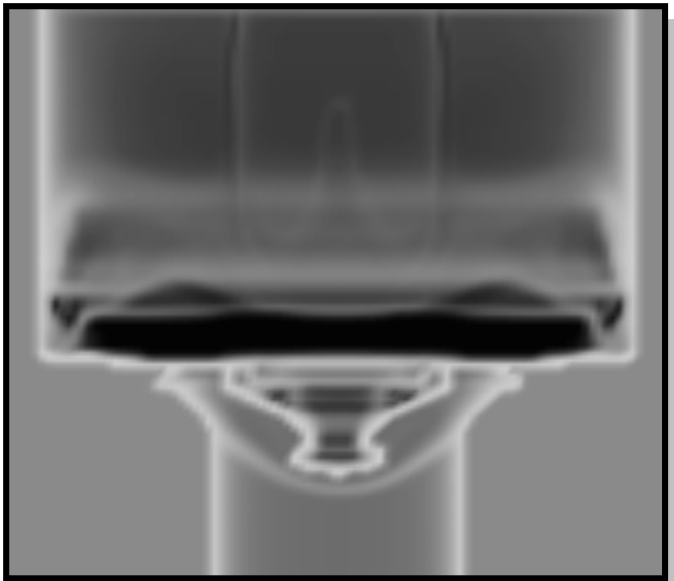
t = 330 ns
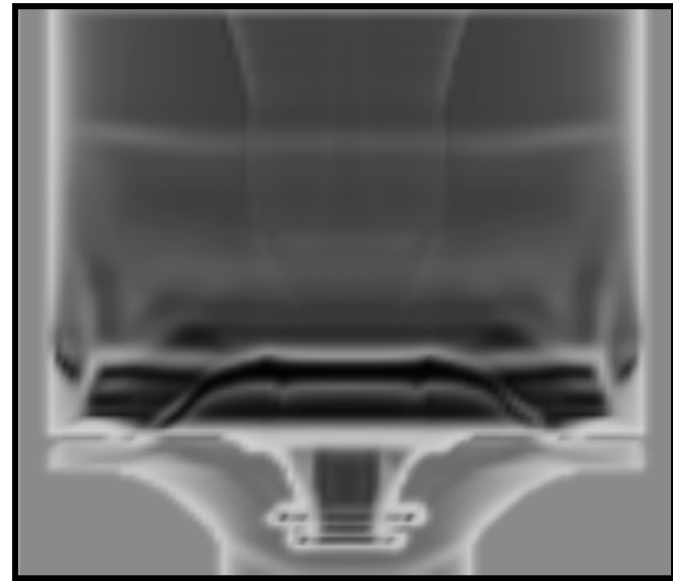
t = 528 ns

We have studied the generation and evolution of radiation-driven jets on both NOVA and Z.

- **The NOVA experiments, in conjunction with the other calculations, have provided validation for the ALEGRA modeling and analyses.**

- **In comparison with the results from NOVA, physical scaling-up of the configuration and using the Z-pinch machine produces similar, although not identical, phenomenology.**

- **Using the ZBL backlighter for diagnostic measurements appears to be feasible for the scaled-up configuration.**

  > **At late times and for high photon energies, optical depths are of order unity.**

- **Next steps and other possibilities:**

  > **Use finer zoning for ALEGRA calculations;**

  > **Use more realistic and representative ZBL spectra;**

  > **Modify Z source to obtain different conditions (*e.g.*, higher temperatures via dynamic hohlraum, multiple and/or colliding jets);**

  > **Examine different configurations of interest, or other degrees of physical scale-up.**

Debris Effects in Partitioned Pipes

R. J. Lawrence,
M. D. Furnish, C. A. Hall,
J. R. Asay, T. G. Trucano,
K. G. Budge

ALEGRA Calculation at $t = 15 \ \mu s$

Density

Pressure

VISAR Probes

Strain Gauges

Experimental Configuration

Z-Pinch

Shock waves moving up pipe wall

Debris penetrating middle partition

Partitions

X-ray Input

Z-Pinch Temperature History

PINCH TEMPERATURE

Raw Data
Smoothed Data
Input for ALEGRA

Temperature (eV)

150

100

50

50 100 150 200

Time (ns)

Long (10 cm) pipe

Incident fluence is ~23 kJ/cm^2
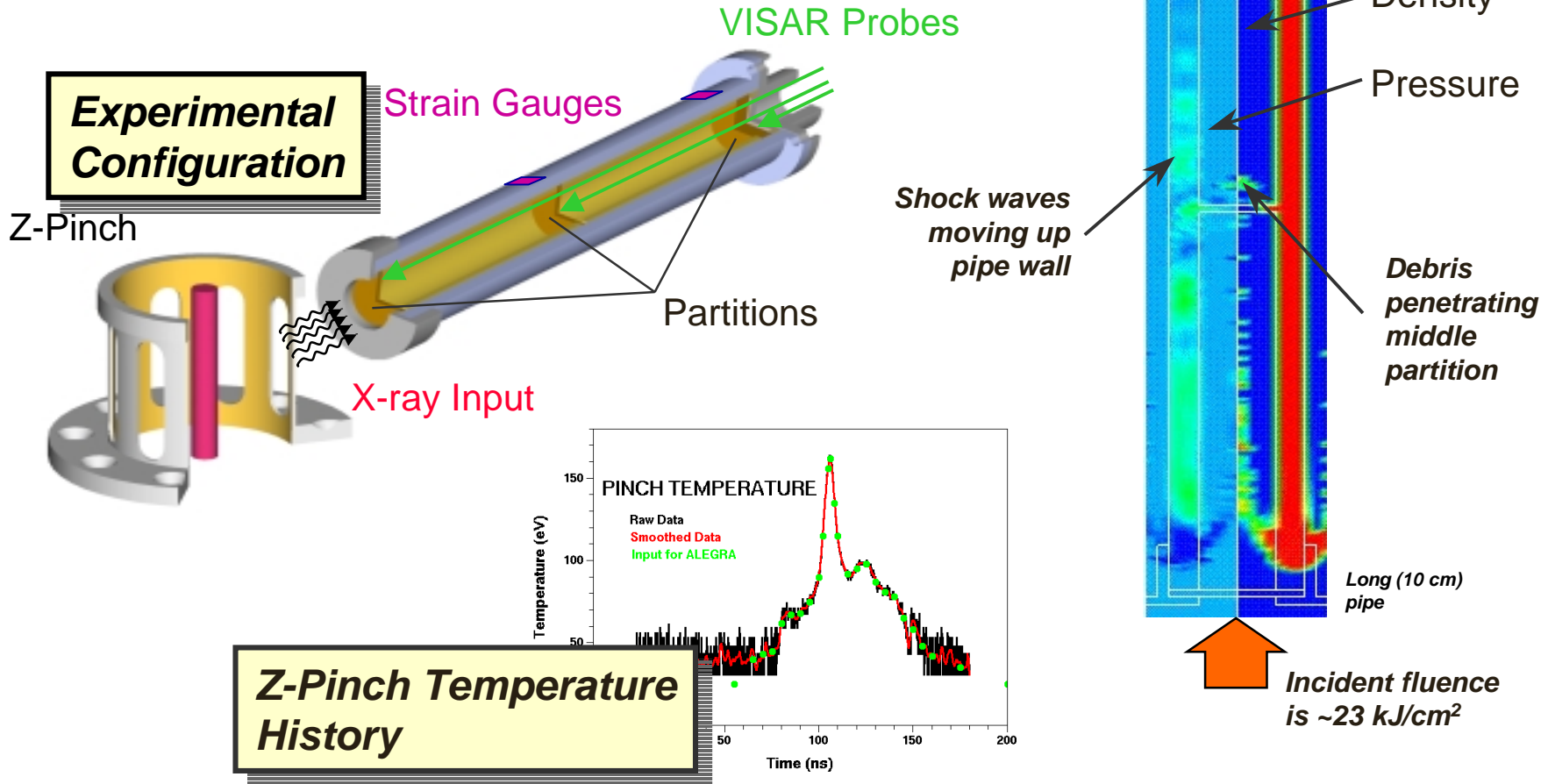
This experiment is being used to study pipe and debris phenomenology using Z and ALEGRA.

VISAR Probes

Strain Gauges

Z-Pinch

X-ray Input

Partitions
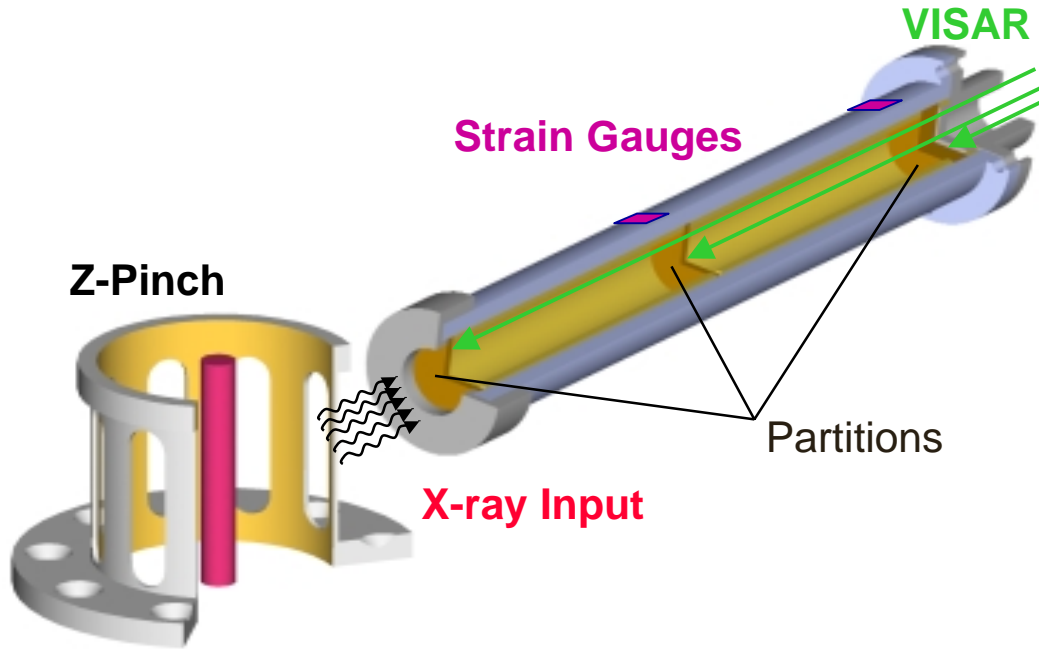
- *Well-characterized radiation environments*
- *Two configurations -- 10 cm and 5 cm long x ~1 cm*
- *Multiple shock diagnostics*
- *Real-time debris generation and barrier failure*

Strategic Intent:

- **Show new capability for Z and Z-pinch in weapon-related applications;**
- **Demonstrate capabilities and expertise of interest to other agencies;**
- **Develop new techniques and diagnostics for future applications, and new areas for ASCI code validation with ALEGRA.**

This slotted-can hohlraum configuration is being used for the partitioned-pipe experiments.
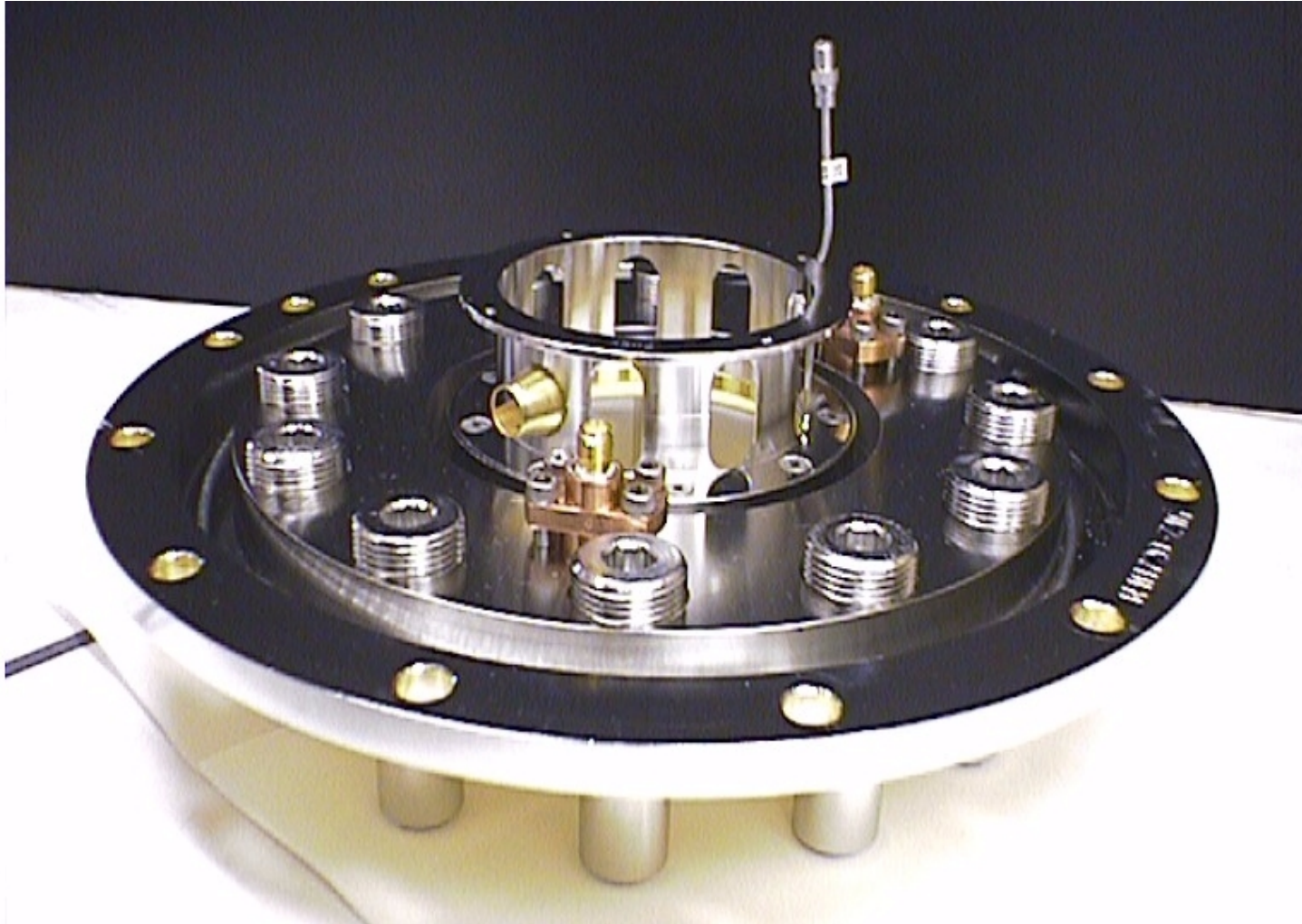
The actual long-pipe sample shows the strain gauges and the attached VISAR probes.
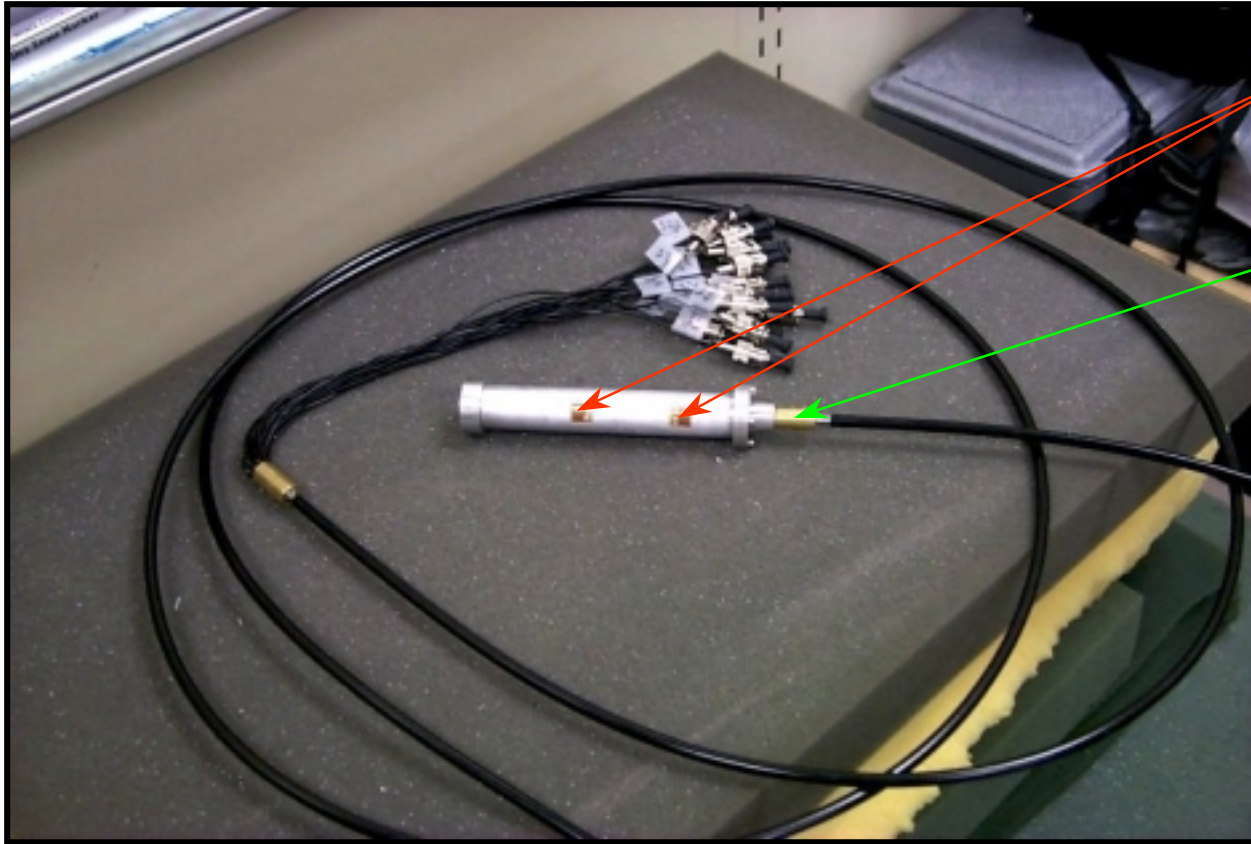
Strain gauges

Connections for VISAR probes

The experiment was successful, and VISAR data was recorded for all three partitions.
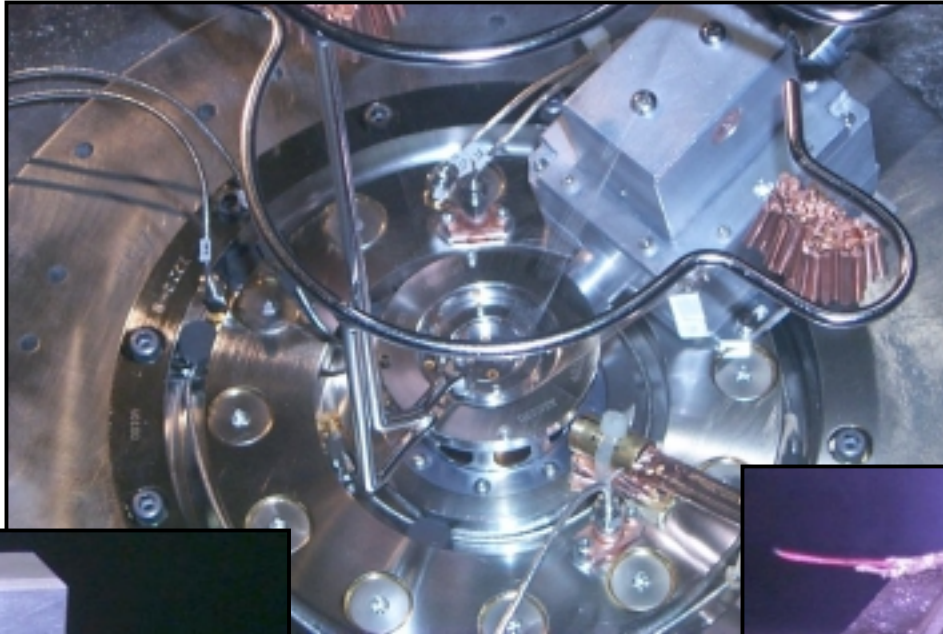
Model target assembly mounted in Z
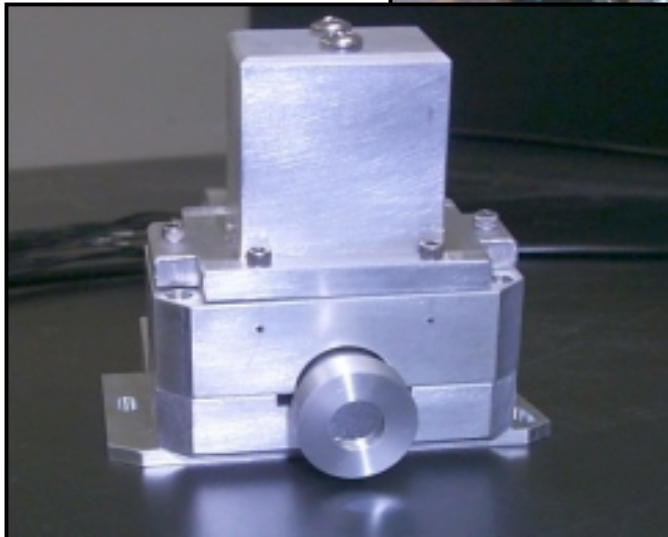
Tunnel model in experimental fixture

Post-shot

Pre-shot
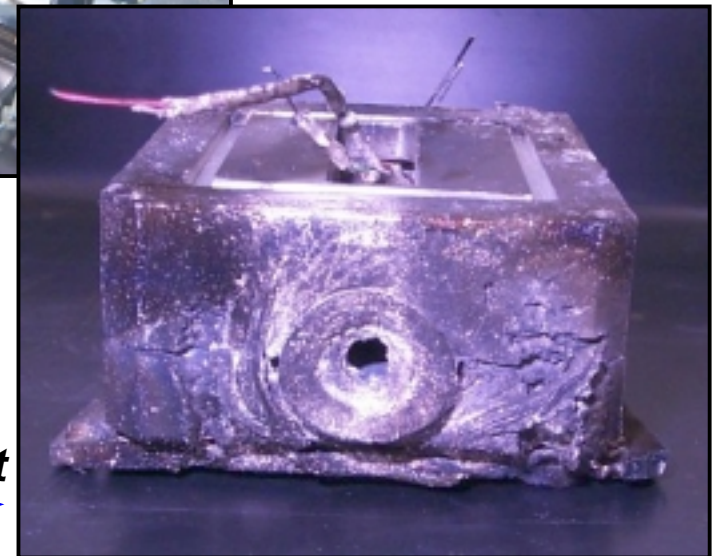
Recovered short pipe provides evidence of response and confirmation of code simulations.

Miniature diagnostics

Original location of partitions

X-rays

Post-Mortem Analysis

- *Erosion mechanisms*
- *Flow phenomenology*
- *Damage mechanisms*

Z-pinch and Target Theory Department

Long Pipe
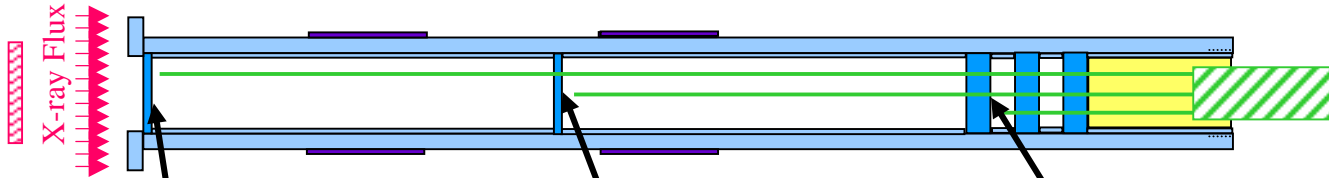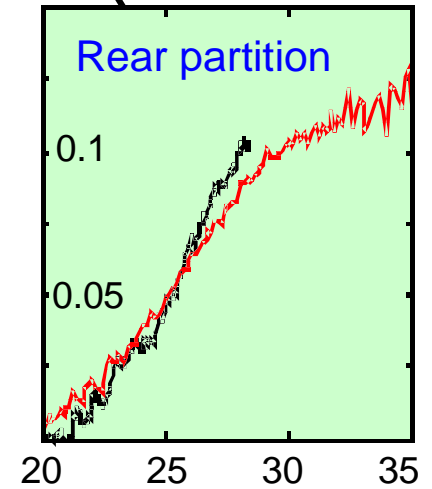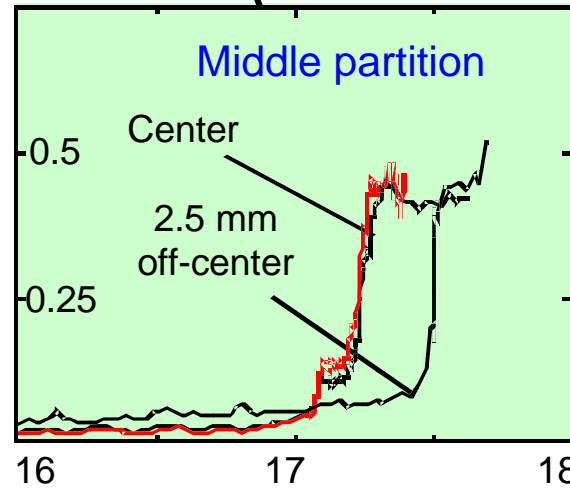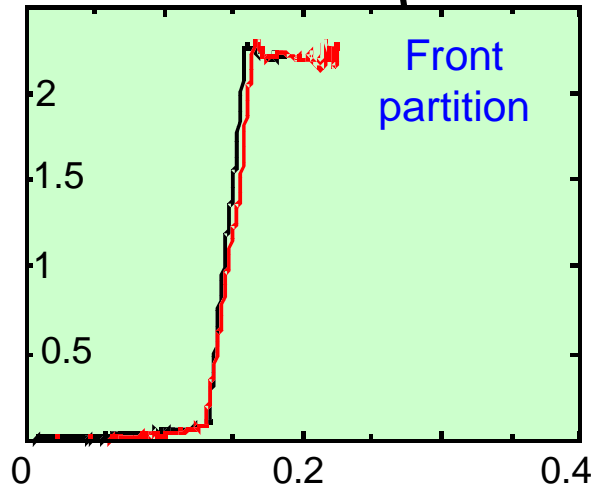
However, the data do show significant scatter, indicating the variable nature of the phenomena.

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Short Pipe
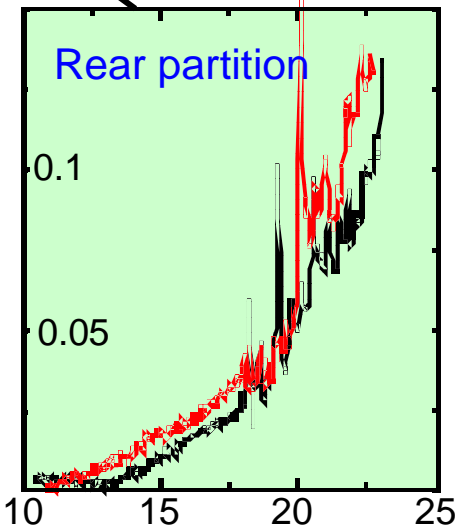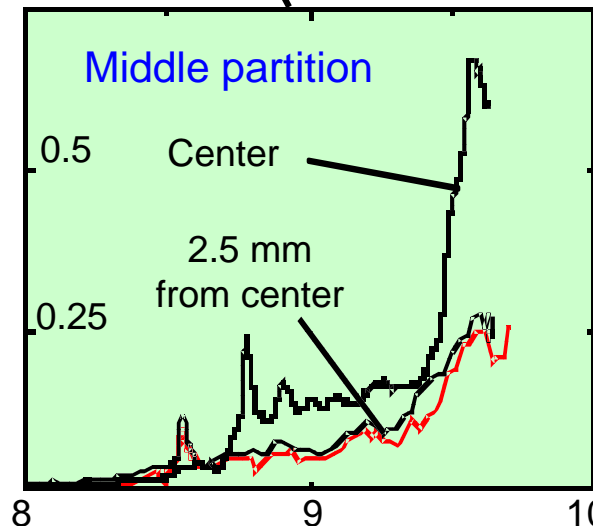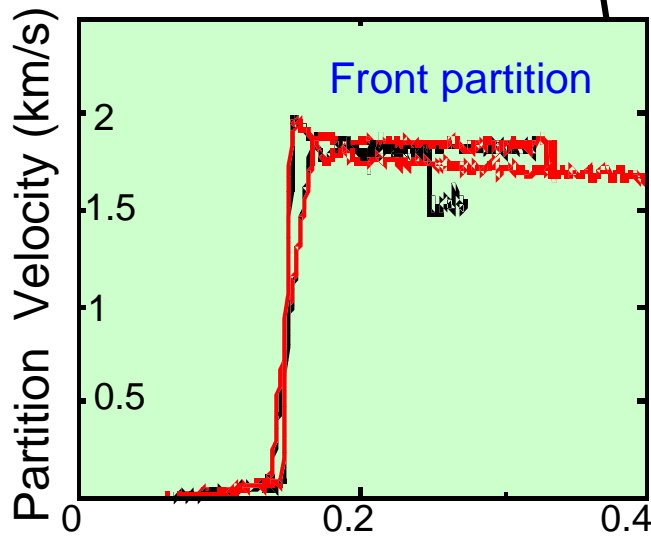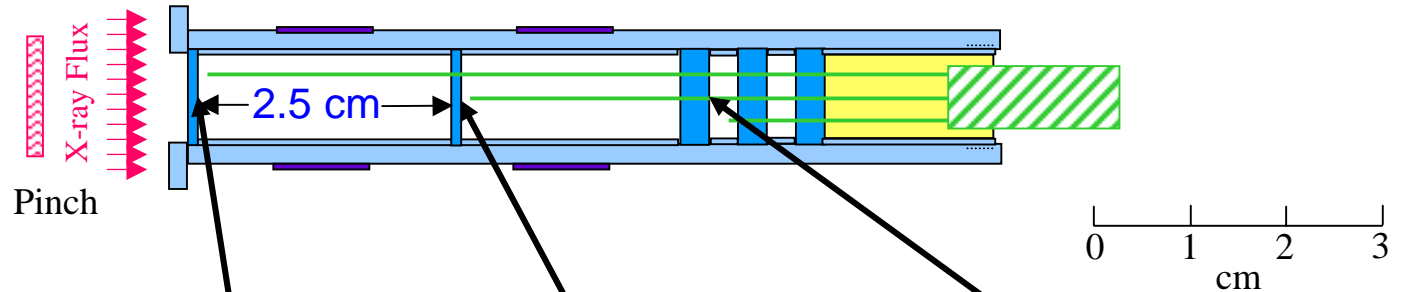
We are using ALEGRA for 2-D Eulerian simulations (post-shot) of the partitioned-pipe response.

Geometric Configuration:
(not to proportional scale)

Radiation input from Z-pinch / hohlraum

Low-density gas with zero opacity

Rear partition

Aluminum pipe

Front & middle partitions

Aluminum retainer ring

Cylindrical axis of symmetry

Low-density gas fill
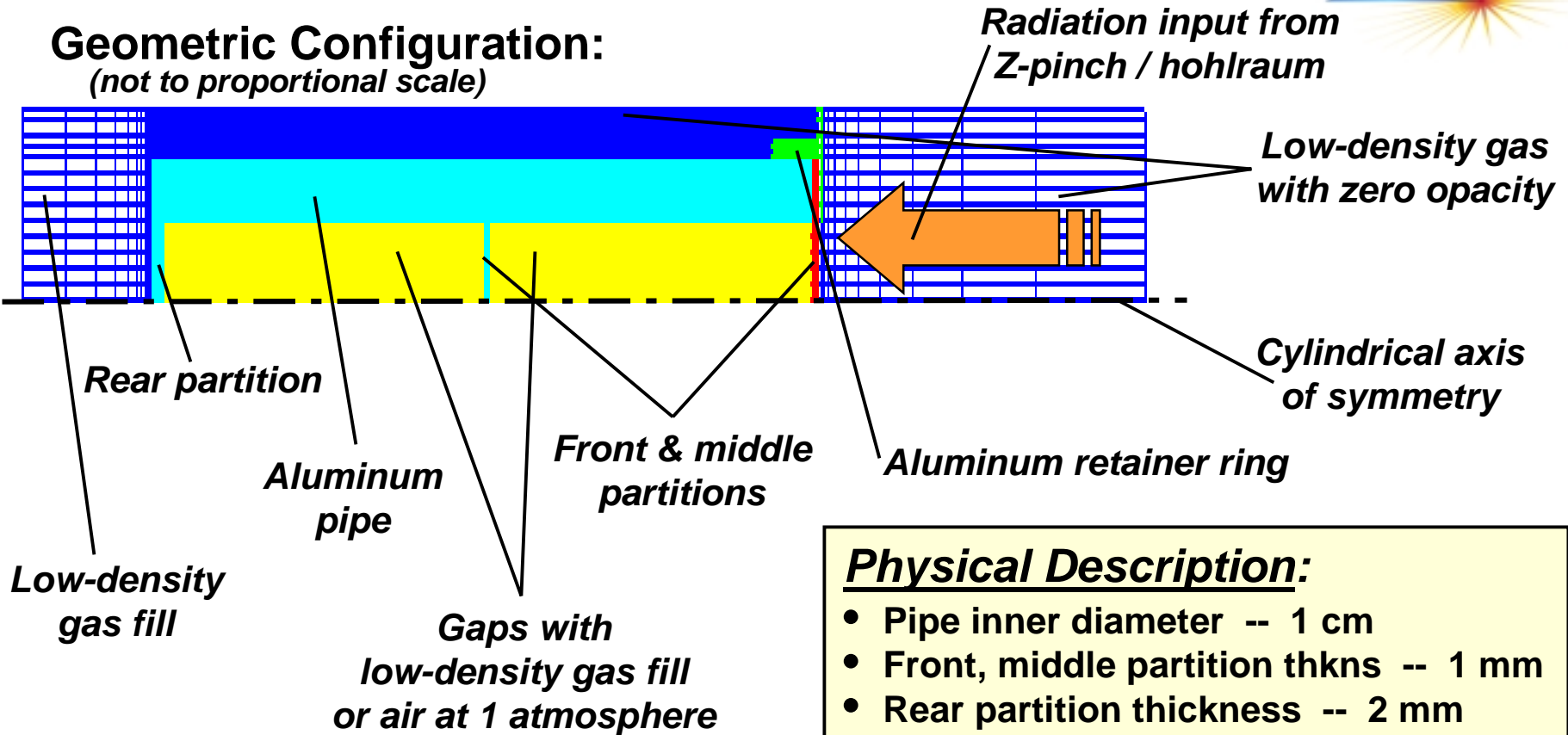
Gaps with low-density gas fill or air at 1 atmosphere

Physical Description:
- **Pipe inner diameter -- 1 cm**
- **Front, middle partition thkns -- 1 mm**
- **Rear partition thickness -- 2 mm**
- **Wall thickness -- ~ 4 mm**
- **Gap length -- 50 mm**
- **Mesh -- ~ 7,000 elements**

"Long" Pipe

The measured output from the Z pinch is being used as input to the post-shot calculations.

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PINCH TEMPERATURE

Raw Data
Smoothed Data
Input for ALEGRA
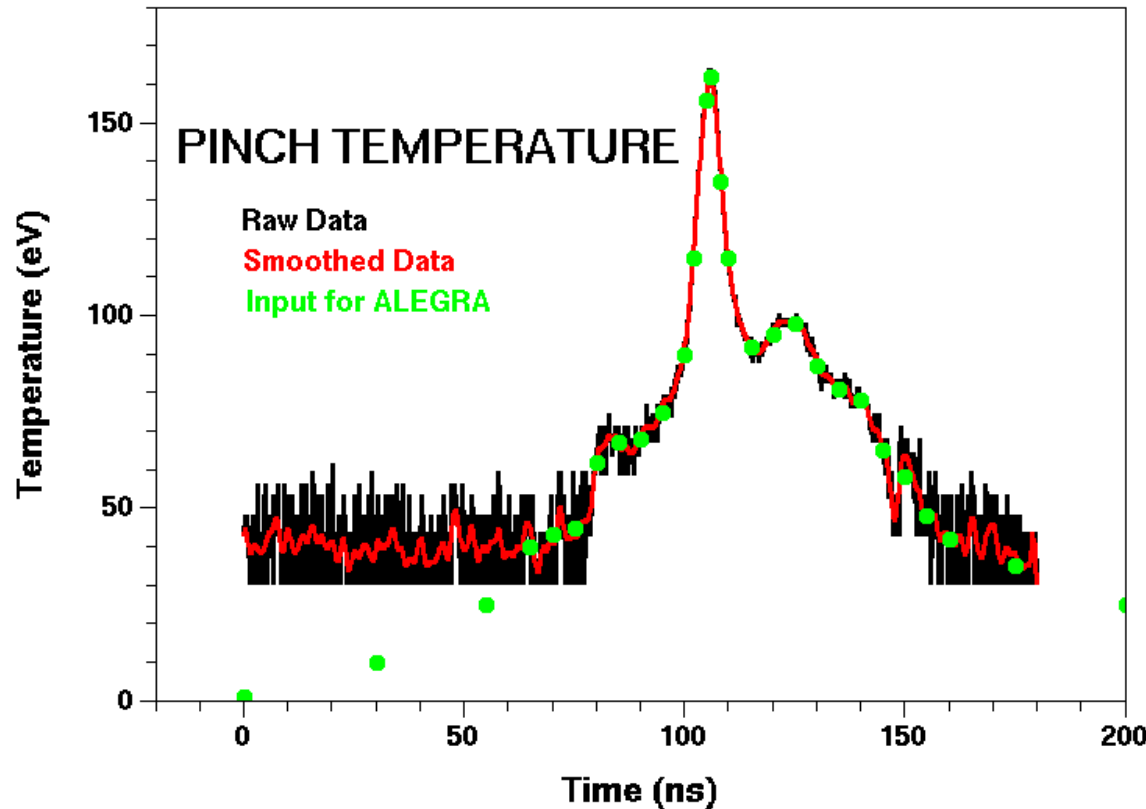
- *The pre-shot estimate was a 40-ns wide triangular pulse peaking at ~150 eV.*

- *The measured output has a peak temperature of ~162 eV, with the indicated time dependence.*

- *Geometric factors restrict the on-target fluence to about 3.3 percent of an equivalent hohlraum at the pinch temperature.*

- *Radiation transport used single-group diffusion; probably adequate for this problem.*

Post-shot calculations were performed with measured radiation input and E-P mat'l response.

The long-pipe calculation shows penetration of the middle barrier at ~13 μs and penetration of the rear barrier at ~36 μs. In both problems the debris is strongly peaked toward the axis.
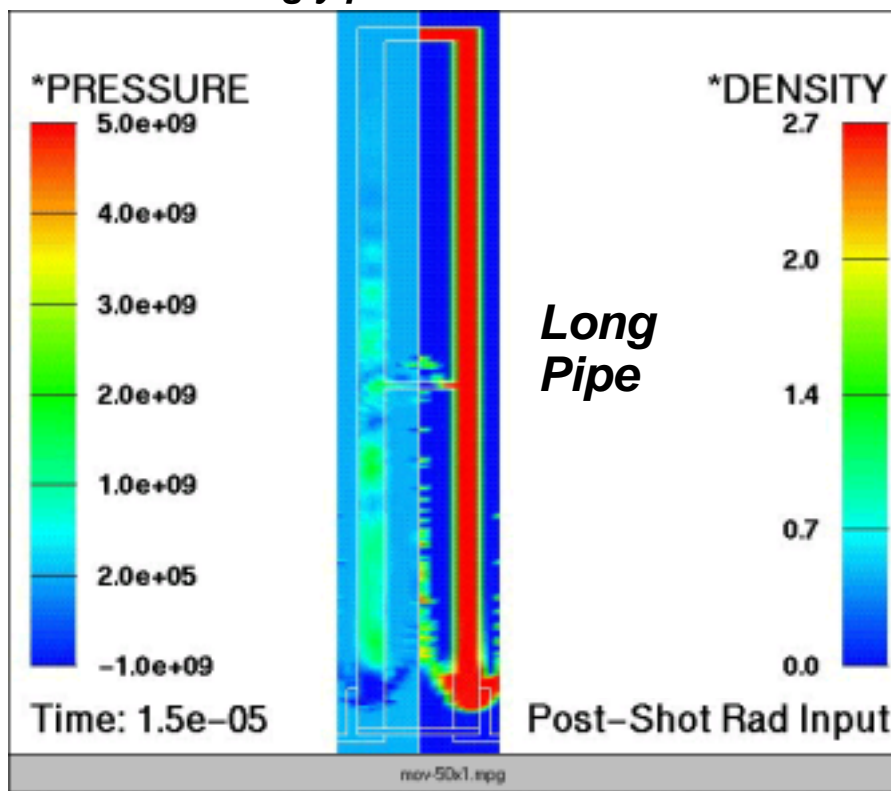
The short-pipe calculation shows penetration of the middle barrier at ~7 μs, and penetration of the rear barrier at ~20 μs. In both cases the stress waves in the tunnel walls precede the debris by roughly a factor of two in time.
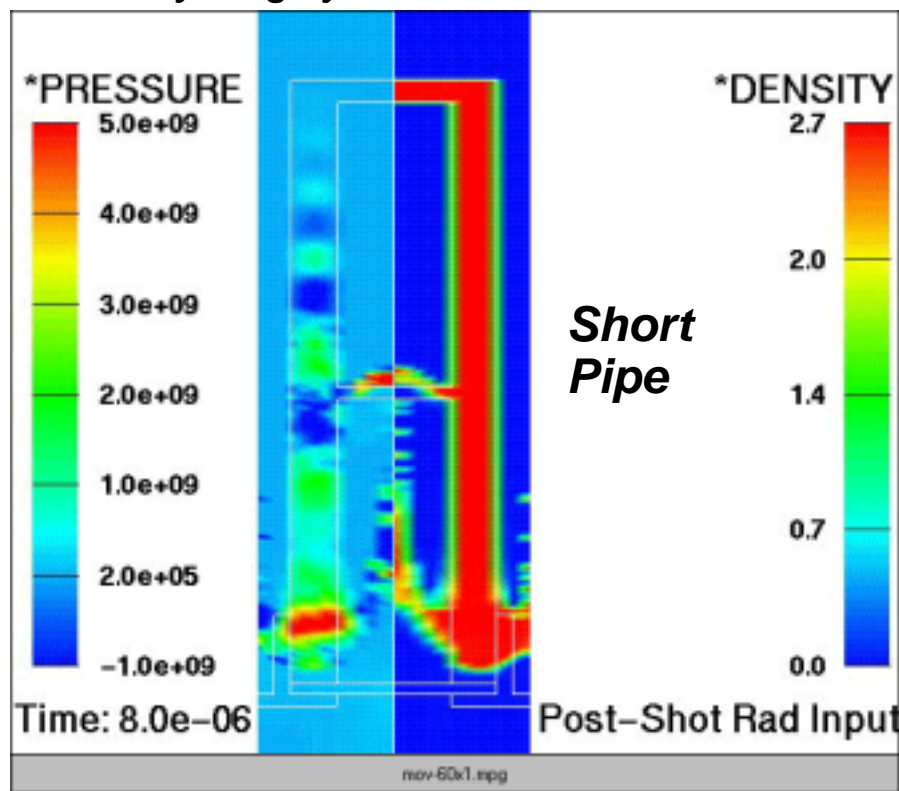
ALEGRA calculations show numerical simulations for pressure histories along pipe wall.

Pressure in Pipe Wall
(Post-Shot / Long-Pipe)
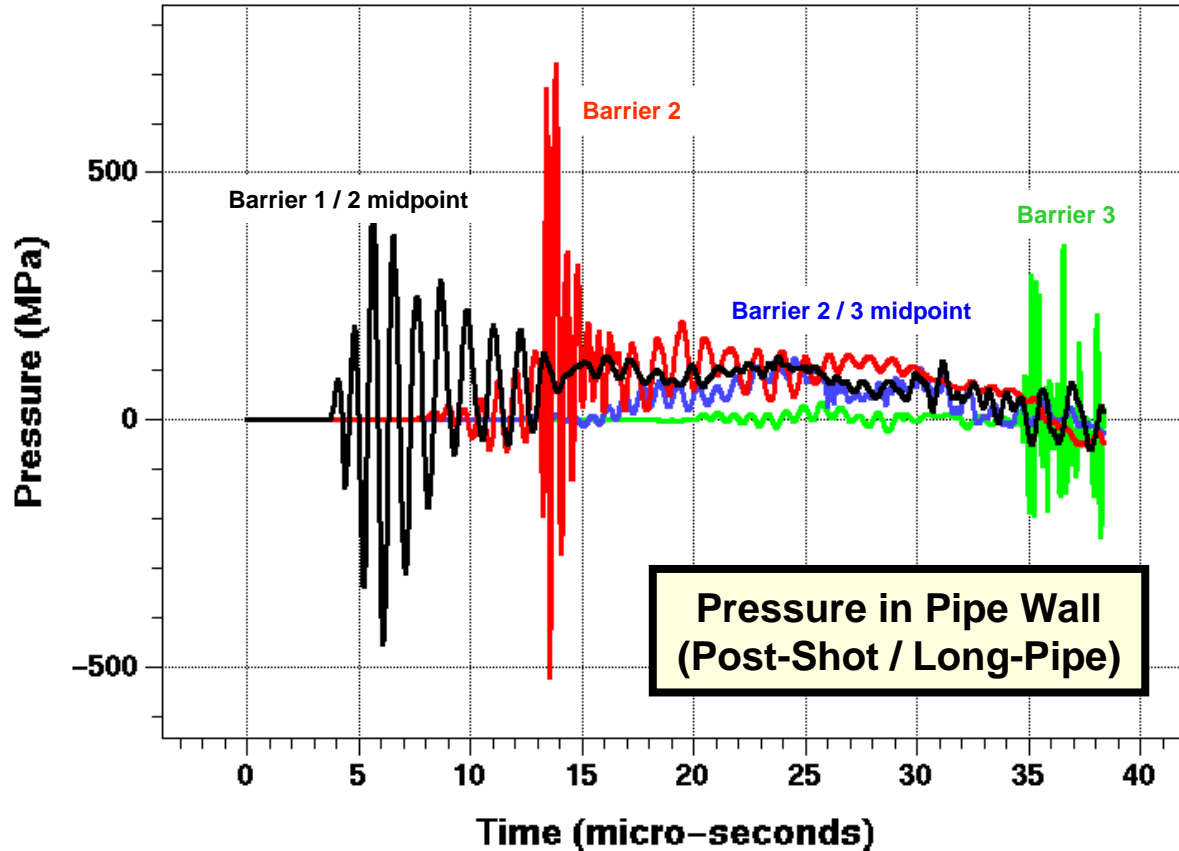
- *These calculated pressure histories are for points half-way through the thickness of the pipe wall at the indicated positions.*

- *The walls and inner partitions were modeled as elastic-plastc materials.*

- *Note the effects of the debris impacts on the traces for partitions 2 and 3.*

- *The midpoint traces do not show these debris-impact signals.*

Velocities for the rear barrier show the effects of both the stress waves in the pipe wall and the debris.

**Rear-Partition Velocities
(Post-Shot / Long-Pipe)**

r = 0.00 cm

r = 0.15 cm

r = 0.3 cm

Axial Velocity (m/s)

500

0

20   25   30   35   40

Time (micro-seconds)
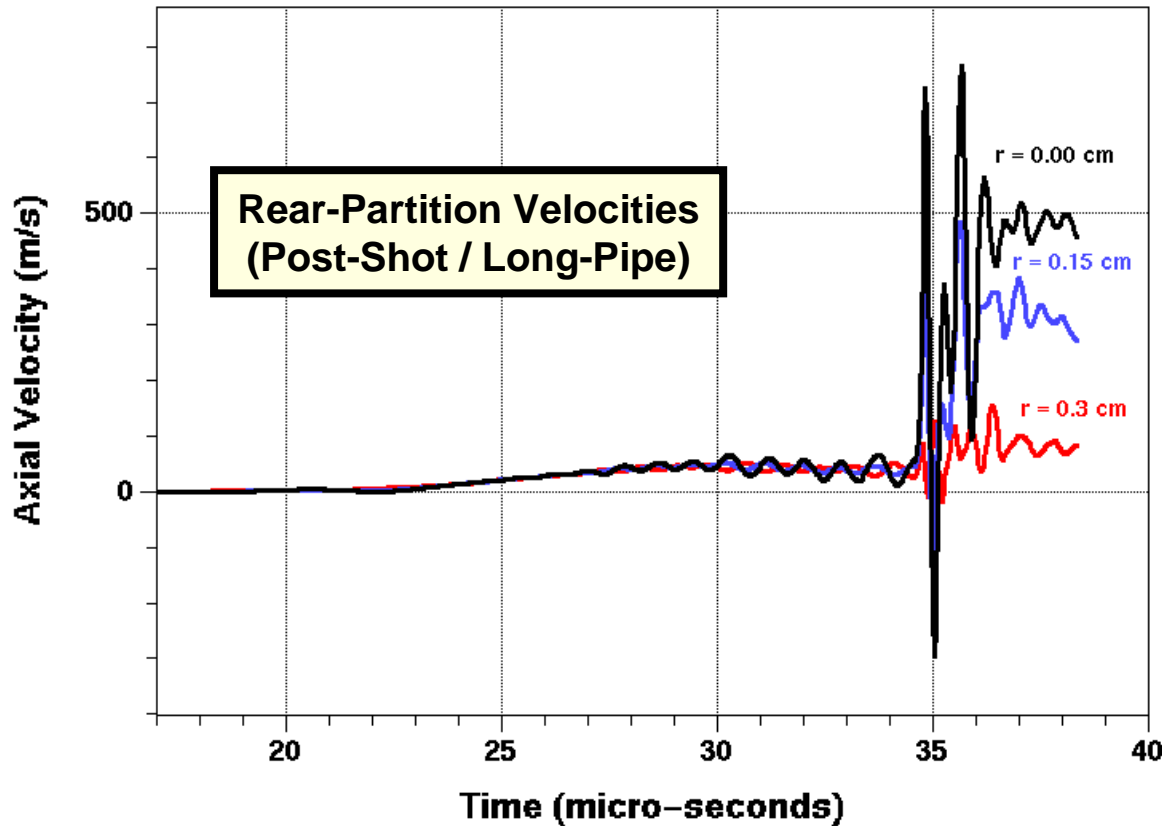
- *The signals from the stress waves in the pipe wall preceding the debris can be seen at both ~20 and ~25 μs; the debris impact on this barrier occurs at ~34 μs.*

- *The calculated rear-surface velocities are relatively low, with a maximum value a little over 0.7 km/s; they are still strongly peaked toward the axis.*

Comparison between experiment and calculation gives only qualitative agreement.

Long Pipe

Black = Experiment

Red = Calculation

Partition ↓	Arrival Time (μs)		Partition Vel. (km/s)		
	Toe	Main	VISAR Precursor	VISAR Main	To next partition
Front On-Axis		0.15		3.9	2.95 3.94
Front Off-Axis	0.06 0.15	0.15	0.07	2.3 3.9	2.88 3.78
Middle On-Axis	12.38	17.09 13.0	0.035	0.45 1.7	2.40
Middle Off-Axis	9.33	17.50 13.5	0.076	0.45 0.2	6.3? 2.40
Rear On-Axis	Not Meas. 22.5	Not Meas. 36	Not Meas. 0.04	Not Meas. 0.48	N. A.
Rear Off-Axis	21.16 22.5	~25? 36	~0.01 0.04	>0.1 0.08	N. A.

- *Times are shifted to superimpose front-barrier peak particle velocity arrival times.*
- *Calculations suggest debris is strongly peaked on axis; middle door velocity measurements suggest asymmetry.*
- *Sectioned short-tunnel shows remaining "door stubs" that are consistent with broad range of debris velocities across tunnel diameter.*

# Source temperatures of 100 eV and 55 eV show qualitatively different response phenomenology.

The debris consists of only low-velocity, high-density material -- the second barrier is penetrated at ~21 μs. The pressure waves precede the debris-generated signals by nearly a factor of two.

Note high-velocity, low-density debris cloud followed by lower-velocity, higher-density material -- the former penetrates the second barrier at ~6 μs, well ahead of any direct pressure waves in the pipe wall.

$\Phi \approx 19$ kJ/cm^2

$\Phi \approx 200$ kJ/cm^2
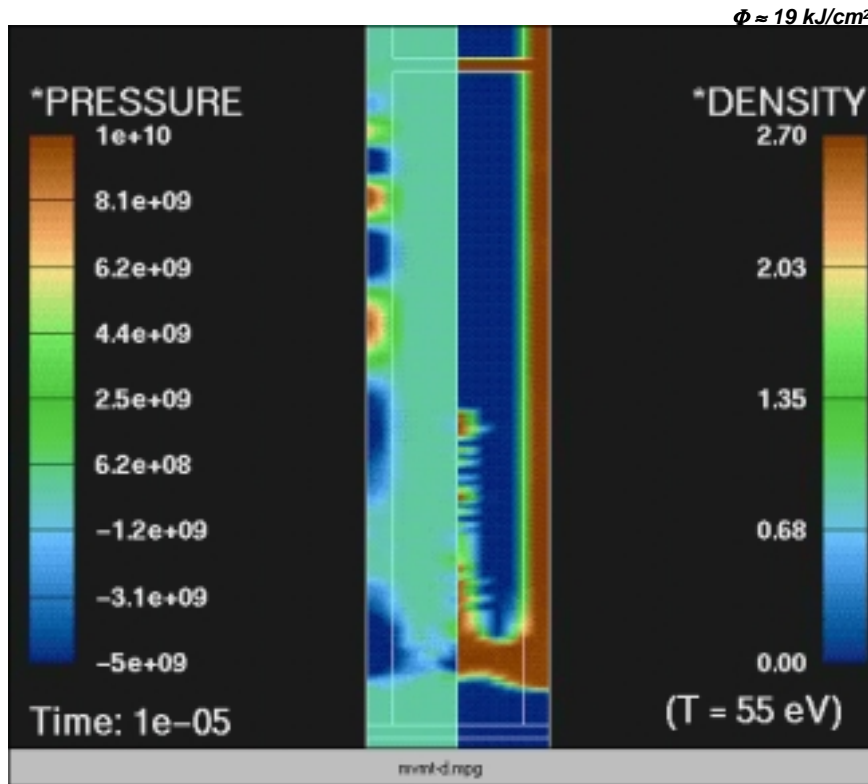
$T_{max} = 55$ eV; $\Phi_{55} \approx \Phi_{100}/11$; 40-ns-wide triangular pulse.
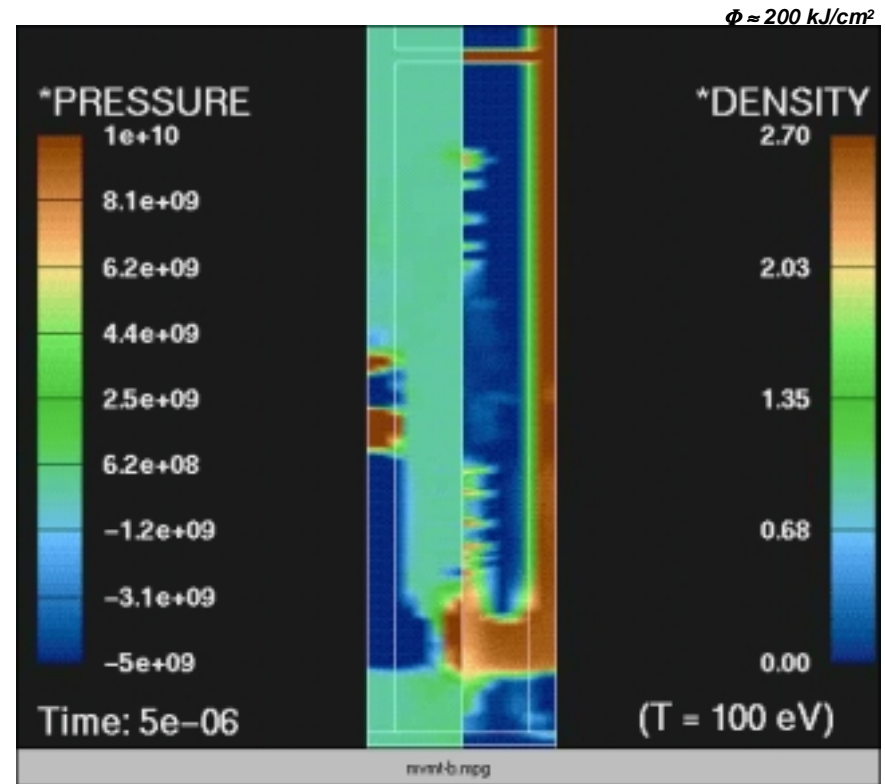
$T_{max} = 100$ eV; $\Phi_{100} \approx 11\ \Phi_{55}$; 40-ns-wide triangular pulse.

Overall conclusions . . .

- **For the radiation-driven jet problem:**
  - > **Validation for the ALEGRA models has been achieved through comparison with the NOVA experiment and other calculations.**
  - > **Experiments scaled up by an order of magnitude on Z show qualitatively similar dynamic response phenomenology.**
  - > **Diagnostics with ZBL are feasible for the scaled-up experiments.**

- **For the partitioned pipe experiment:**
  - > **Qualitatively different response phenomenology results from variations in loading conditions.**
  - > **Measured velocity histories were not well matched, but discrepancies may be due to uncertainties in radiation environment.**
  - > **ALEGRA was used in a predictive mode to help with experimental design, and new applied capabilities for both Z and ALEGRA have been demonstrated.**

- **The ASCI code ALEGRA is under continuing development, but is being used routinely to address practical issues associated with experimental design and applied system-level response.**